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Factors Affecting the Planform of the Sturgeon River

by

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A THESIS
SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH
IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE
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Abstract

This study investigates the channel pattern of the Sturgeon River and the factors which affect it. Six short reaches were selected for study. Along these, data as to channel perimeter sediment, channel cross-section, valley and channel slope, and valley bottom width were collected. The factors which might account for the downstream change in channel pattern along each reach are discussed. Simple and multiple regression analyses are used to describe the relationships between the collected data and the planform variables: wavelength, radius of curvature, amplitude and sinuosity. The Sturgeon River data relations are compared to those given in the literature. Overall, slope and channel width are significant in determining the planform along these reaches. The channel perimeter sediment and the valley bottom width are important in places.

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Table of Contents

Chapter Page

1. INTRODUCTION 1

1.1 Objectives 1

1.2 Summary of Methods 4

1.3 Description of Study Area 5

1.4 Conclusion 13

2. A Review of the Literature on Meandering Channel Patterns 15

2.1 Introduction 15

2.2 Discharge Relations 15

2.3 Meander Wavelength 16

2.4 Compound Meanders 19

2.5 Other Measures of Meander Planform 21

2.6 Influence of Channel and Valley Slope 23

2.7 Channel Cross-sectional Form 36

2.8 Flow in Bends 38

2.9 Channelisation 39

2.10 Influence of Channel Perimeter Sediment and Sediment Load 40

2.11 Channels with Low Slopes and Fine Sediments 44

2.12 Effects of Riparian and Aquatic Vegetation 46

2.13 Conclusions 49

3. TECHNIQUES OF DATA COLLECTION AND ANALYSIS 50

3.1 Introduction 50

3.2 Channel Cross-sectional Data 50

3.2.1 Field Measurement of Cross-sections 51

3.2.2 Fitting the Cross-sections 53

3.2.3 Bankfull Cross-sections 57

3.3 Sediment Sampling 63

3.3.1 Gravel sampling 63

3.3.2 Sampling of Fine Sediments 65

3.4 Laboratory Analysis of Sediment Size 67

3.4.1 Hydrometer Analysis 68

3.4.2 Sieving 70

3.4.3 Reproducibility of Laboratory Analyses 71

3.5 Computation of Sediment Size Measures 73

3.5.1 Graphical and Moment Measures 73

3.5.2 Other Measures of Sediment Size Characteristics 76

3.6 Channel Planform Measures 77

3.6.1 Sinuosity 77

3.6.2 Radius of Curvature, Wavelength, and Amplitude 78

3.7 Channel and Valley Slopes 80

3.8 Valley Widths and Meander Belt Width 83

3.9 Data Analysis 83

3.9.1 Correlation 83

3.9.2 Regression Analysis 84

4. DESCRIPTIONS OF THE STURGEON RIVER REACHES 89

4.1 Introduction 89

4.2 Reach A 91

4.3 Reach B 114

4.4 Reach C 133

4.5 Enlarged Bends 149

4.6 Reach D 156

4.7 Reach E 170

4.8 Reach F 182

4.9 General Comments and Conclusions 198

5. ANALYSIS OF DATA 200

5.1 General Introduction 200

5.2 Channel Perimeter Sediments and the Width to Depth Ratio 202

5.3 Planform and Channel Cross-sectional Characteristics 205

5.3.1 Meander Wavelength and Channel Width 205

5.3.2 Meander Wavelength and the Channel Width:Depth Ratio 209

5.3.3 Radius of Curvature and Channel Width and Width to Depth 212

5.3.4 Sinuosity, Width and Width to Depth 215

5.3.5 Amplitude and Channel Width and Width to Depth 217

5.3.6 Conclusions on Planform and Channel Cross-sectional Relations 217

5.4 Channel Pattern and Slope 222

5.5 Planform and Sediment Characteristics 224

5.6 Planform Interrelations 232

5.7 Multiple Regressions and Correlations for the Planform Variables 238

5.7.1 Introduction 238

5.7.2 Relations for Radius of Curvature 240

5.7.3 Relations for Meander Wavelength 243

5.7.4 Relations for Meander Amplitude 247

5.7.5 Relations for Sinuosity 250

5.7.6 Summary of Multiple Regression Relationships 253

5.8 Conclusions 254

6. CONCLUSIONS 263

REFERENCES 273

APPENDIX I - Laboratory Procedures for Sediment Size Analysis 290

APPENDIX II - Radius of curvature, wavelength, and amplitude of the simple and small meanders of the Sturgeon River reaches 296

APPENDIX III - Sediment Size Data from Laboratory Analyses of the Sturgeon River bed and bank samples ..298

APPENDIX IV - Detailed regression analysis results for the Sturgeon River data sets 311

List of Tables

Table Page

2.1 Slope-discharge relationships from the literature. 27

2.2 Data from the literature for channels with cohesive material in the channel perimeter. 30

3.1 Water discharges at the times that the below-water cross-sections were measured (Canada Inland Waters Directorate, 1980). 60

4.1 Averaged valley bottom widths and simple or large meander amplitudes for reaches A to C. 95

4.2 Distance downstream from Big Lake in km regressed on channel perimeter sediment variables and cross-section variables for Reach A. 97

4.3 Observed widths, Wo, first-break-in-slope widths, Wfb, and valley-flat break-in-slope widths, Wvf, for the Sturgeon River reaches. 102

4.4 Definitions of some features associated with meandering channels. 105

4.5 The observed channel width to maximum depth ratio, (W/Dx)o, for Reach A. 111

4.6 Distance downstream from Big Lake, dds, in kilometres regressed on radius of curvature, Rc, wavelength, L, and amplitude, Amp, all in metres. 116

4.7 Distance downstream from Big Lake in km regressed on channel perimeter sediment variables and cross-section variables for Reach B. 119

4.8 The valley bottom width and the ratio of amplitude to wavelength for the large meanders of reaches A, B, and C. 127

4.9 Averaged planform data for the Sturgeon River from the downstream portion of Reach B to the downstream portion of Reach C for the simple or small meander data. 134

4.10 Distance downstream from Big Lake in km regressed on channel perimeter sediments and cross-section variables for Reach C. 136

4.11 Valley bottom widths along Reach D. 160

4.12 Distance downstream from Big Lake (km), dds, regressed on channel perimeter sediment variables and cross-section variables for Reach D. 162

4.13 The observed width to maximum depth ratio, (W/Dx)o, and the first-break-in-slope width to maximum depth ratio, (W/Dx)fb, for Reach D. 164

4.14 Valley bottom widths along Reach E. 172

4.15 Distance downstream from Big Lake (km), dds, regressed on channel perimeter sediment variables and cross-section variables for Reach E. 180

4.16 Valley top widths and depths of incision along the Lily Incision. 187

4.17 Meander belt widths and valley bottom widths for Reach F. 189

4.18 Distance downstream from Big Lake in km regressed on channel perimeter sediment variables and cross-section variables for Reach F. 190

4.19 The form of cross-section 3 of Reach F immediately after the diversion (1966-67) (Alberta Department of Highways, 1966) and in July, 1979. 197

5.1 A diagram of the relationships between the width to depth ratios and the channel perimeter sediment variables for the Sturgeon River data. 203

5.2 A diagram of those relationships between wavelength and channel width which are statistically significant for the Sturgeon River data sets. 207

5.3 A diagram of those relationships between wavelength and the width to depth ratios which are statistically significant for the Sturgeon River data sets. 210

5.4 A diagram of those relationships between radius of curvature and width and between radius of curvature and width to depth which are statistically significant for the Sturgeon River data sets. 213

5.5 A diagram of those relationships between sinuosity and width and sinuosity and the width to depth ratio which are statistically significant for the Sturgeon River data sets. 216

5.6 A diagram of those relationships between amplitude and width and between amplitude and width to depth which are statistically significant for the Sturgeon River data sets. 218

5.7 A diagram of the relationships between planform and channel slope or valley slope which are statistically significant for the Sturgeon River data sets. 223

5.8 A diagram of the relations between wavelength and the channel perimeter sediments which are statistically significant for the Sturgeon River data sets. 226

5.9 A diagram of the relationships between radius of curvature and the channel perimeter sediments which are statistically significant for the Sturgeon River data sets. 227

5.10 A diagram of the relationships between amplitude and the channel perimeter sediments which are statistically significant for the Sturgeon River data sets. 228

5.11 A diagram of the relationships between sinuosity and the channel perimeter sediments which are statistically significant for the Sturgeon River data sets. 230

5.12 Wavelength, L, radius of curvature, Rc, and amplitude, Amp, all in metres, and their association with the arc angle, θ, in degrees. (a) Calculated L for specific Rc and θ values. (b) Calculated meander wavelengths for varied θ and specific Rc values. (c) Calculated meander wavelengths for varied θ and specified Rc, combined. (d) The effects of the arc angle, θ, on the interrelations between wavelength and radius of curvature for the data from tables 5.18a, b, and c; the relations between radius of curvature, wavelength and amplitude and the arc angle for the Sturgeon River data of reaches A, B, and C. 234

5.13 A diagram of the statistically significant multiple regression relations for radius of curvature data, Rc, for the Sturgeon River data sets. 241

5.14 A diagram of the statistically significant multiple regression relations for wavelength data, L, for the Sturgeon River data sets. 244

5.15 A diagram of the statistically significant multiple regression relations for amplitude data, Amp, for the Sturgeon River data sets. 248

5.16 A diagram of the statistically significant multiple regression relations for sinuosity data, Sin, for the Sturgeon River data sets. 251

List of Figures

Figure		Page
1.1	(a) The location of the Sturgeon River basin. (b) The Sturgeon River basin downstream of Big Lake (Simpson, 1977, Figure 3).	2
2.1	The relationships between sinuosity and valley slope from laboratory stream experiments (Schumm and Khan, 1972, p.1761, Figure 6).	26
2.2	Channel slope vs. bankfull discharge for Alberta rivers (Kellerhals *et al.*, 1972) and for channels with a high proportion of silt and clay in the channel perimeter.	28
2.3	Valley slope vs. bankfull discharge for channels with a high proportion of silt and clay in the channel perimeter (see Key on Figure 2.2).	34
2.4	Channel slope vs. mean discharge for channels with a high proportion of silt and clay in the channel perimeter (see Key on Figure 2.2).	35
3.1	Comparison of measured ice-surface width with measured water-surface width when small bars occur along the channel margin.	55

3.2 Extrapolation of a valley-flat break-in-slope cross-section. 62
3.3 Gravel bed sampling method. 66
3.4 (a) Measuring radius of curvature, Rc, meander wavelength, L, and meander amplitude, Amp. (b) Measuring meander belt width, MBW. 79
3.5 Measuring meander amplitude, Amp, and wavelength, L, for large bends within compound meanders. 81
4.1 The Sturgeon River along reaches A, B and C. 92
4.2 Variations in meander wavelength and amplitude with distance downstream for Reach A. 93
4.3 Channel cross-sections along Reach A (Yaremko, 1968; Szabon, 1975). 99
4.4 Cross-section of a point bar in the downstream portion of Reach A. 104
4.5 A scroll bar located on a point bar at cross-section 14 in the downstream portion of Reach A. 106
4.6 Bed and water surface slopes along reaches A to C. (a) Bed profile from Big Lake to the railroad bridge (Yaremko, 1968). (b) Water surface slopes from Szabon (1975) and the Alberta Planning

Division (unpub.). 107

4.7 Generalised diagram of changes in channel characteristics of some suspended load systems (from Morton and Donaldson, 1978, p.1035, Figure 6). 110

4.8 Characteristics of the compound portion of reaches A to C. (a) The small meanders with alternate bars colonised by emergent aquatic plants. (b) The compound meanders at higher discharges, when the alternate bars of the small meanders are submerged. 115

4.9 Sediment size characteristics from the channel perimeter of Reach B. (a) Mean sediment sizes of the bed and bank samples vs. distance downstream. (b) Percent of sand and gravel in the bed samples vs. distance downstream. 121

4.10 Channel cross-sections along Reach B. 122

4.11 The ridge-depressions of the large amplitude meander portion of Reach B. 124

4.12 Comparison of sinuous and unstable meanders formed on a hydrophobic surface (from Gorycki, 1973, figures 5 and 7). (a) Sinuous pattern. (b) Unstable pattern, which is produced by increasing water flow beyond that required to induce meandering. 131

4.13 Channel cross-sections along Reach C of the Sturgeon River.. 138

4.14 Sediment size characteristics from the channel perimeter of Reach C. 4.14 (a) Mean sediment sizes of the bank samples vs. distance downstream for Reach C. (b) Mean sediment sizes of the bed samples vs. distance downstream for Reach C. 140

4.15 Sketch of point benches found where the channel pattern is contorted. 143

4.16 (a) Locations of possible formation of separation zones along a bend, shown in plan (Rozovskii, 1961, p.5, Figure 3). (b) Plan view of a tight bend showing the water surface contours in millimetres (Rozovskii, 1961, p.116, Figure 44). 145

4.17 Cutoffs in the contorted portion of Reach C. 147

4.18 An enlarged bend between Reach C and Reach D, in the contorted portion of the Sturgeon River. (a) The bend cross-section. (b) A sketch of the banks above water level. (c) A sketch of the planform of the bend. 150

4.19 Abrupt-angle eddy formation (from Carey, 1969, p.985, Figure 3). 152
4.20 A sketch of an enlarged bend between Reach C and Reach D, in the contorted portion of the Sturgeon River. 155
4.21 The Sturgeon River along Reach D. 157
4.22 Reach D: (a) before the diversion, 1924; (b) during the diversion, 1962; (c) after the diversion, 1976; ....,158
4.23 Channel cross-sections along Reach D of the Sturgeon River. 163
4.24 Sediment size characteristics from the channel perimeter of Reach D. (a) Mean sediment sizes of the bank samples vs. distance downstream for Reach D. (b) Mean sediment sizes of the bed samples vs. distance downstream for Reach D. 165
4.25 The central portion of Reach D, where a meandering pattern seems to be reforming after artificial straightening. 169
4.26 The Sturgeon River along Reach E. 171
4.27 Meander scars in the upstream portion of Reach E. 174
4.28 Surficial geology in the Reach E region (from Bayrock, 1972) and the proposed 'meltwater channel' location. 175
4.29 Channel cross-sections along Reach E of

the Sturgeon River. 177

4.30 Sediment size characteristics from the channel perimeter of Reach E. (a) Mean sediment sizes of the bank samples vs. distance downstream for Reach E. (b) Mean sediment sizes of the bed samples vs. distance downstream for Reach E. 179

4.31 The Sturgeon River along Reach F. 183

4.32 Reach F: (a) before; (b) during; (c) after the 1966-67 diversion. 184

4.33 The Lily Incision (from Bayrock, 1972). 186

4.34 Sediment size characteristics from the channel perimeter of Reach F. (a) Mean sediment sizes of the bank samples vs. distance downstream for Reach F. (b) Mean sediment sizes of the gravel samples vs. distance downstream for Reach F. 192

4.35 Channel cross-sections along Reach F. 193

5.1 Geometrical relationships between the arc angle, θ, radius of curvature, Rc, wavelength, L, and amplitude, Amp. 233

5.2 Wavelength - width data points from Leopold and Wolman (1960) which are within the range of the Sturgeon River channel width data. 258

List of Symbols

%SCBK, %SCBD	Percent of silt and clay in the channel banks, in the channel bed.
%SBK, %SBD	Percent of silt in the banks, in the bed.
%CBK, %CBD	Percent of clay in the banks, in the bed.
MBK	Mean bank sediment size, mm.
MBD	Mean bed sediment size, mm.
Mo,Mfb	Schumm's weighted mean percent silt-clay = (%SCBK x W + %SCBD x 2Dx)/(W + 2Dx), for the observed cross-sectional data, for the first-break-in-slope cross-sectional data.
d50	Median grain size.
A	Channel cross-sectional area, m^2.
Ao, Afb, Avf	Channel cross-sectional area at the observed water level, at the first-break-in-slope water level, at the valley-flat break-in-slope water level, m^2.
W	Channel width, m.
Wo, Wfb, Wvf	Channel width at the observed water level, at the first-break-in-slope water level, at the valley flat water level, m.
Dm, Dx	Mean channel depth, maximum channel depth, m.
(Dm)o, (Dm)fb, (Dm)vf	Mean channel depth at the observed water level, at the first-break-in-slope water level, at the valley-flat break-in-slope water level, m.

Sc, Sv	Channel slope (i.e. water surface slope), valley slope.
VBW	Valley bottom width, m.
MBW	Meander belt width, m.
L	Meander wavelength, m.
Rc	Meander radius of curvature, m.
Amp	Meander amplitude, m.
Sin	Channel pattern sinuosity = (distance along the channel centreline) / (straight line distance from the top of the reach to the bottom of the reach).
Q	Water discharge.
Qb	Bankfull discharge.
Qm	Mean discharge.
Qmaf	Mean annual flood discharge.
Qfb	Discharge associated with the first-break-in-slope water level.
dds	Distance downstream from Big Lake, km.
t	Student's t statistic.
r, R	Sample correlation coefficient for simple correlation, multiple correlation.
r^2, R^2	Coefficient of determination for simple correlation, multiple correlation.

1. INTRODUCTION

1.1 Objectives

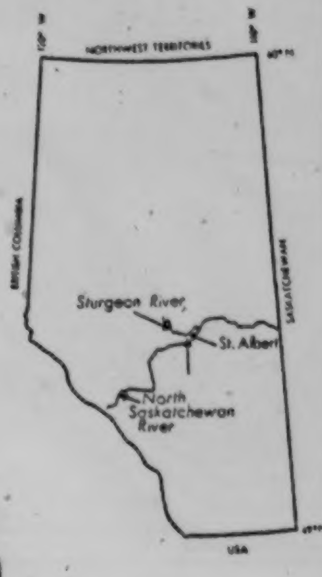
The aim of this study is to investigate the channel pattern of Sturgeon River from Big Lake to the North Saskatchewan River and the factors which affect it. The location of the Sturgeon River, a meandering stream in central Alberta, and the locations of the study reaches along the Sturgeon River are shown on Figure 1.1.

With increasing distance downstream, the channel pattern of the Sturgeon River changes, although the water discharge remains relatively constant. It has been found that the geometry of river meanders is related to stream discharge (e.g. Leopold, Wolman, and Miller, 1964; Dury, 1964; and Carlston, 1965), although there is usually much scatter in the regression lines fitted to the data. Discharge data from two gauge stations, one near Big Lake, and the other near the mouth of the Sturgeon River (Figure 1.1), indicate that only a very small downstream increase in discharge occurs along the study reach. Thus, the Sturgeon River offers the opportunity to consider other variables which might affect the meander geometry and so account for some of the scatter associated with meander geometry - discharge relationships.

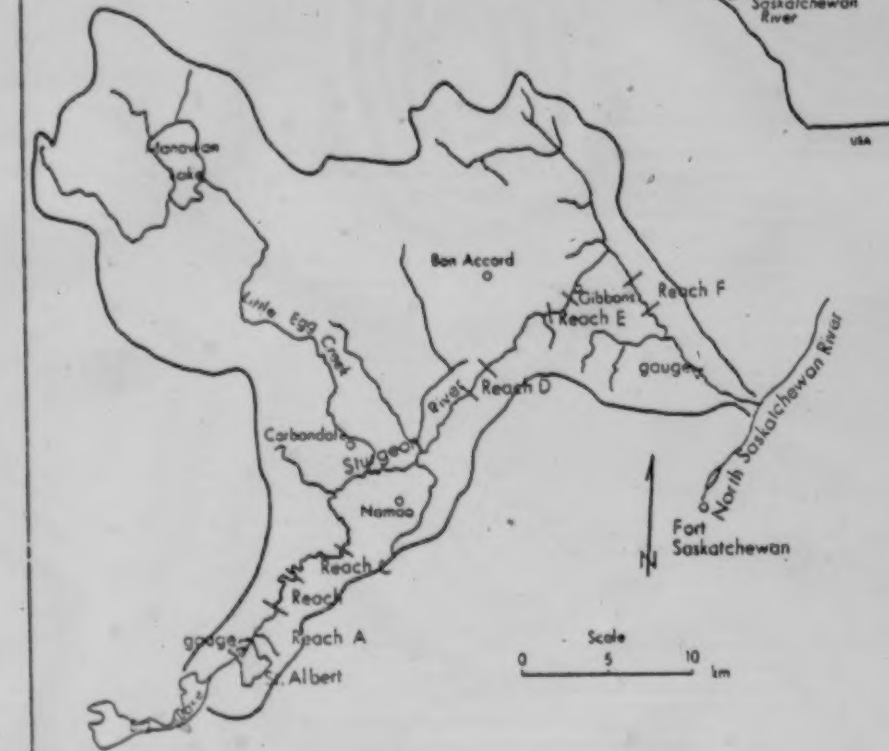
Also, along part of this portion of the Sturgeon River, there is little evidence for lateral and downstream

Figure 1.1

(a) The location of the Sturgeon River basin.



(b) The Sturgeon River basin downstream of Big Lake (Simpson, 1977, Figure 3).



migration of the meander form through erosion along the outside banks of bends and deposition along the inside banks, as is commonly described for meandering streams (e.g. Friedkin, 1945). A comparison of air photographs of the Sturgeon River dating from 1924 to 1976 reveals that much of the study reach shows very little evidence of progressive lateral or downstream meander migration for this period of time. Floodplain features and channel cross-sectional features which are associated with the meandering process are only sometimes observed. Thus, although the river has a meandering planform, evidence of the meandering process is not always apparent. This allows comparison of the characteristics of a channel which has a meandering planform but few of the features generally associated with the meandering process to the characteristics of more "typical" meandering channels described in the literature. Some portions of the study reach have been artificially straightened. This permits the examination of the effects of externally imposed changes on the pattern.

Six short reaches along the Sturgeon River between Big Lake and the North Saskatchewan River were selected for study (Figure 1.1). Each of these reaches exhibits a downstream change in planform. From a review of the literature (Chapter 2), variables were selected for measurement which are thought to be relevant to the channel pattern: sediment size in the channel perimeter, channel and valley slope, cross-sectional form and valley bottom width.

Each of the reaches is described first in primarily qualitative terms with respect to its channel pattern, sediments, cross-sectional form, slope, and valley form. Then the quantitative relationships found for the Sturgeon River data are described and compared to those given in the literature for meandering natural rivers and laboratory streams.

1.2 Summary of Methods

In order to investigate the changes in the channel pattern downstream, reaches were selected in which changes in the channel pattern occur. In general, the aim was to include several meander wavelengths for each of the patterns existing in the reach. To investigate the changes in the channel pattern through time, two reaches where patterns have been modified by man were also selected. These two reaches were chosen to include several meander wavelengths upstream and downstream of the modification.

Both bed and bank sediments were sampled along reaches A to F. The sediment sizes were analysed in the laboratory using hydrometer and sieving techniques. Channel cross-sections were surveyed in this study or obtained, along with channel slope data, from Yaremko (1968), Szabon (1975) and Alberta Environment Planning Division (unpub.). The collected data were statistically analysed using regression and correlation analyses to look for relations between the planform characteristics and sediment, slope, cross-sectional form and valley form.

1.3 Description of Study Area

The reach from Big Lake (53 37' N Lat., 113 40' W Long.) to the mouth on the North Saskatchewan River, (53 46' N Lat., 113 10' W Long.) is approximately 92 km in river length. The total basin area is 3354 km². There are two gauges along the study reach, one at St Albert, and one near the mouth of the river (Figure 1.1). The record for the station at St Albert is short. From 1913 to 1927, a manual gauge was used and the flows were not usually recorded during the winter months. There is then a break in the record until March 1976, from which time a continuous recording gauge has been used for recording data from March to October (Canada, Inland Waters Directorate, 1978; Canada, Inland Waters Directorate, 1979). The record for the station near the mouth of the river begins in 1913 using a manual gauge to make some miscellaneous measurements. From 1914 until 1923 measurements were taken continuously through the year, with a manual gauge. From 1927 until 1931, and from 1935 until present, a manual gauge has been used to measure flows from March to October (Canada, Inland Waters Directorate, 1978; Canada, Inland Waters Directorate, 1979).

Only one stage-discharge curve exists for the station at St Albert because of the short length of record for this station (May, pers. comm., 1978). There are five curves for the station near the mouth of the Sturgeon River. These curves cover the last 24 years and do not show a constant trend towards either degradation or aggradation.

Mean monthly flow, based on 59 years of record from the gauge near Fort Saskatchewan, ranges from about 0.6 to 2 cumecs during fall and winter, reaching maximum values in the spring of about 10.5 cumecs and then dropping off in the summer to 1.5 to 4.5 cumecs (Simpson, 1977). Even though the total discharge through the reach is nearly constant from St Albert to the mouth of the river, the bankfull discharge values are variable along the study reach. At St Albert, bankfull is 14.2 cumecs, for Reach B bankfull discharge is 7.6 cumecs, and downstream of Reach B the bankfull discharge increases, reaching almost 226.5 cumecs at the mouth (Simpson, 1977). This very large bankfull value at the downstream end of the reach is probably calculated based on a low terrace level (e.g. Kellerhals and Church, 1980).

In April 1974, the largest discharges recorded along the Sturgeon River occurred. At St Albert, the measured peak was 104 cumecs on April 26, and at the station near the mouth, the measured peak flow was 115 cumecs on April 27 (Szabon, 1975).

Peak flow travel time through the whole Sturgeon system is typically 12 days to St Albert, and 15 days to the mouth. The only major tributary along the study reach is Little Egg Creek (Figure 1.1). Tributary inflows along the Sturgeon

River system usually occur well in advance of the mainstream peaks, resulting in very little increase in peak flows in a downstream direction (Simpson, 1977).

Minimum discharges have fallen to zero or near zero at both stations in all months except April and May (Simpson, 1977). Mean discharge for the station near the mouth is 4.1 cumecs, based on a 42 year record (Neill, *et al.*, 1970).

The Sturgeon River is the source of water for one country-residential subdivision, just downstream from St Albert. Water is not withdrawn for municipal water supplies, although the Sturgeon River does carry effluent from municipal sewage for Gibbons and Bon Accord. There is also limited withdrawal for irrigation and stockwatering (Simpson, 1977).

With regards to the groundwater flow systems in the basin, Bibby (1974a,b) determined that, at all depths considered, water levels showed a marked correlation with surface topography and the (1974a, p. 5):

> "...flow directions have a downward component relative to the water table over most of the area. Areas of upward flow are restricted to narrow bands coincident with the valleys."

Bibby (1974b) also stated that the flow pattern immediately around the Sturgeon Valley cannot be clearly defined with the data available to him.

The general topography of the region is flat to gently rolling, river incision producing the major relief. Along most of the study reach, the Sturgeon River is deeply incised, the maximum relief being about 46 m (Bibby, 1974a).

The basin of the study reach is underlain by the Wapiti Formation, a poorly indurated non-marine formation of Late Cretaceous Age (Green, 1972). Green described this formation as being composed of clayey sandstone, bentonitic mudstone and bentonite, with scattered coal beds. Montmorillonite is the dominant clay mineral of the bedrock and, because of this, the formations in the Edmonton area have a high plasticity (Locker, 1973). The formation has a strike northwest to southeast, and a dip of about 4 m per km to the southwest (Ground-Water Consultants Group, 1977). Where rivers cut through the poorly indurated Upper Cretaceous bedrock of central Alberta, the valley wall slopes very often show slumping (Locker, 1973; Thompson, 1970; Thompson and Yacyshyn, 1977). Slumping occurs frequently along the Sturgeon Valley walls where the river cuts deeply into the Wapiti formation. Part or all of the channel perimeter of the Sturgeon River is composed of bedrock in places.

Above the bedrock are discontinuous deposits known as the Saskatchewan Gravels and Sands. These preglacial deposits cap bedrock uplands and also form valley fill and terrace deposits. They are predominantly composed of quartzose sandstone, jasper, and local bedrock fragments (Westgate, 1969).

There have been several studies on the preglacial channel deposits around the study area. Carlson (1967) determined that the Sturgeon River downstream from Big Lake follows preglacial thalwegs for at least part of its course. According to Carlson (p.7), the Sherwood Ridge, "probably the expression of a relatively erosion resistant layer within the Edmonton Formation", formed a watershed. Where this ridge intersects the present Sturgeon River along and downstream of Reach C, the valley becomes steep-sided and narrow. Most of the preglacial valleys are broad and gently sloping. Therefore, Carlson postulated that this section of the valley may not have been in existence preglacially, being the result of breaching during glacial or recent times.

Topp (1969) proposed a preglacial thalweg along the Sturgeon Valley near the North Saskatchewan River, referred to herein as the "Lily Incision" (Bibby, 1974b). Bibby (1974a) indicated a preglacial thalweg flowing continuously from near Gibbons to Big Lake, and no thalweg along the Lily Incision. Stein (1976) also did not show a preglacial thalweg along the Lily Incision. Westgate (1969) stated that the Sturgeon Valley downstream of Big Lake is "undoubtedly of glacial origin" (p. 133). According to Kathol and McPherson (1975, p.23):

> "Data are not sufficient to determine whether the bedrock erosion along the Sturgeon River Valley near St Albert took place in postglacial times."

Usually the bedrock and/or the Saskatchewan Gravels and Sands are overlain by till. In the study area, the till forms ground moraine, producing a fairly level to gently rolling surface (Bayrock, 1972). The till layer is commonly thin where it caps bedrock highs and thicker along the buried valleys (Bayrock and Berg, 1966). The amount of gravel-sized particles present in the till is variable, although generally less than ten percent. The gravel is a mixture of the local bedrock, igneous and metamorphic rocks from the Canadian Shield, and Devonian carbonate fragments from the Shield margin. The till is calcareous because of these carbonate fragments. The clay fraction in the till is predominantly of montmorillonite, from the local bedrock, causing the till to be sticky (Bayrock and Hughes, 1962). Some investigators recognized two tills in the Edmonton area based on colour, fabric and structural differences (Rains, 1969a; Westgate, 1969). In places the Tofield Sands, stratified quartzose sand deposits, occur between the two till layers (Westgate, 1969). Bayrock and Hughes (1962) and Bayrock and Berg (1966) postulated only one till layer.

Above the till deposits are sediments associated with Glacial Lake Edmonton. The lake was short-lived (Hughes, 1958) and there are no well-defined beaches. At the base of the thicker sections of Glacial Lake Edmonton sediments is a deposit of sand. The basal sands and silts grade into bedded silts and clays which become more clayey towards the top. Thinner sections are composed of only varved silt and clay layers with an uppermost clayey layer (Bayrock and Hughes, 1962). The bedded silts and clays form steep bluffs in places along the Sturgeon Valley. The Sturgeon Valley Fluvial Sand outcrops along the Sturgeon River downstream of

Big Lake, and occurs further downstream where it underlies Glacial Lake Edmonton silts and clays. Like the other basal sand units in the area, it is composed of cross-bedded fine to medium sand with some silt and the deposits are from 0.6 to 9 m thick (Bayrock and Hughes, 1962). The Sturgeon River cuts through deposits of a pitted delta south of Bon Accord, where Reach D is located. The delta is composed of fluvial sands, some silt, minor clay and occasional till pockets. Once the main outlet for Glacial Lake Edmonton ceased to be active, only a few small lakes remained, one of which was Big Lake (Bayrock and Hughes, 1962). Bayrock (1972) determined that the Sturgeon Valley follows the valleys cut by glacial "meltwater channels" in some locations, although in many places the valley appears to have been cut postglacially through preglacial and/or glacial sediments.

Two studies have been completed on small tributaries of the North Saskatchewan River in the Edmonton Area, one on the Whitemud Creek (Rains, 1969b) and the other on Weed Creek (Shelford, 1975). Both channels are thought to have three or four terrace levels which correlate with terrace levels identified by Westgate (1969) along the North Saskatchewan River in the Edmonton Area. There have not been any studies of terraces along the Sturgeon River Valley, although Kellerhals *et al*. (1972) indicated that there exists one fragmentary terrace level in the reach around the lower gauge. The long profiles of Weed Creek (Shelford, 1975), Whitemud Creek (Rains, 1969b), and the Sturgeon River downstream of Big Lake are all convex, with oversteepened lower reaches. The convexity of these profiles may be due to adjustment to lowering of the North Saskatchewan River which acts as a base level for these streams.

The effects of postglacial uplift on the Sturgeon River have not been determined. According to Bayrock (1964), postglacial uplift in the Edmonton area has been more rapid in the west than in the east. The Edmonton area was glaciated by Laurentide Ice and, therefore, isostatic rebound due to the unloading of glacial ice should produce greater uplift in the east. Thus, Bayrock attributes the observed uplift to tectonic origins. However, the uplift pattern which Bayrock proposed is based on Glacial Lake Edmonton shoreline positions which are poorly defined.

The soils of the Sturgeon Basin are predominantly chernozems on the fairly level plain areas, and regosols on alluvium in the river valley (Bowser *et al.*, 1962). The natural vegetation of the area is classified as Aspen Poplar, composed of aspen poplar, balsam poplar, with scattered patches of white and black spruce, and some pine (North, 1976). Much of the level upland area has been cleared and is being used for agricultural or residential purposes. Near St Albert, the land use along the Sturgeon Valley is urban and suburban residential as well as some agricultural and recreational use. Further downstream most of the land in the Sturgeon Valley is eith forested, especially where the valley walls are steep, or cleared and used for pasture or crops. Most of the small tributary valleys are narrow, steep-sided,and forested.

The climate of the area (Bibby, 1974b) is continental, with relatively warm summers (mean temperature, May to September inclusive is 13.3 C), and cold winters (mean temperature November to March inclusive, is -8.8 C). Mean annual precipitation is 444.5 mm. About 70 percent of this falls as rain and most of this occurs in June, July and August. From November to March, the precipitation is usually in the form of snow. The average snowfall per year is 1270 mm but ranges from 254 mm to 2286 mm. The ground is frozen about 150 days per year on the average.

1.4 Conclusion

This chapter has provided a description of the study area and a brief introduction to the nature of the study undertaken on the Sturgeon River channel pattern. Gauge records show that the Sturgeon River's water discharge increases very little from St Albert to near the river's mouth. Consequently, one of the variables affecting planform is held nearly constant. The Sturgeon River has a meandering channel pattern but shows little evidence of the meandering process. Data were collected from six short reaches of the Sturgeon River between Big Lake and the North Saskatchewan River. These data have been used to compare the relations between the planform characteristics and the other factors thought to be affecting the planform and to compare the Sturgeon River data relationships with relationships given in the literature.

2. A Review of the Literature on Meandering Channel Patterns

2.1 Introduction

One way in which a stream adjusts to imposed environmental conditions is by modification of its channel pattern. Figure 3.4 illustrates some of the dimensions used to characterise channel pattern. Some of the variables which are thought to affect the channel's planform are water discharge, sediment load and sediment in the channel perimeter, valley and channel slope, channel cross-sectional form, and vegetation in and around the channel. The following chapter is a brief summary of some of the literature which concerns how these variables interact, particularly with respect to meandering channel patterns.

2.2 Discharge Relations

In much of the early literature regarding river activity, there is an implicit recognition that water discharge is a control of river morphology (see Dury, (1954) for a review of this literature). Over the past few decades, a common approach in river morphology has been to develop empirical relations between water discharge and variables such as channel width, meander planform, and channel slope. The relations are usually expressed as power equations plotted on log-log plots. There has been criticism of this approach because some of these relations appear to have no physical significance (Ackers and Charlton, 1970d) and because some of the variables do not change linearly with discharge but rather have thresholds where abrupt transitions occur (Richards, 1973, 1977). Nevertheless, the log-log regression relations with discharge are relatively simple to calculate, and often can provide an overall picture of the relationship under consideration.

2.3 Meander Wavelength

Meander wavelength, L, (Figure 3.4) is frequently used to characterise meander geometry in morphometric relationships. Chately (1940) was one of the first to suggest the use of meander wavelength in river studies. There is general agreement in the literature that L is related statistically, either directly or indirectly through its relation to channel width, to some measure of the river's discharge. The relation between wavelength and discharge usually involves a large scatter of points about the regression line. There exist practical difficulties in measuring L (Ferguson, 1975). Also, because natural rivers are subject to a range of discharges, it becomes necessary to choose a value which will be most closely related to L, referred to as the "dominant discharge" (e.g. Benson and Thomas, 1966).

Several workers have equated dominant discharge with a discharge at or near bankfull (Inglis, 1941; Leopold, Wolman and Miller, 1964; Ackers and Charlton, 1970c). It is this value to which the channel cross-sectional size appears to be adjusted which implies that this is an important channel-forming discharge. Harvey (1969) has pointed out the problems in defining "bankfull", and the possible variations in bankfull along a stream and between streams of different character.

Others have proposed that discharges smaller than bankfull are more significant. Carlston (1965) showed that mean annual discharge and mean discharge for the month of maximum discharge are more strongly related to L than is bankfull discharge. Using data from a variety of stations in the United States, Benson and Thomas (1966) related discharge values to maximum sediment load (only suspended load data were available) in order to determine which discharge value is responsible for transporting the greatest amount of sediment. They found that most suspended sediment is carried during a range of flows much smaller than bankfull discharge. Similarly, Harvey (1975), using data from three English rivers, showed that discharges smaller than bankfull are most strongly related to L.

There has been some discussion in the literature as to whether L is directly or indirectly related to water discharge. Because the statistical relation between L and W, channel width, is stronger than that between L and Qb, bankfull discharge, Leopold and Wolman (1957) concluded that meander wavelength is related only indirectly to water discharge, through a direct relation with channel width. Some field data for natural rivers indicate that L is typically between 7 and 10 times the value of channel width (Leopold and Wolman, 1960). However, Brice (1973), for example, found much greater variations in meander loop size along the White River.

According to the literature, the relationship between meander wavelength and channel width remains near linear despite different channel perimeter characteristics and through almost eight orders of magnitude, from small laboratory streams to the Gulf Stream (Leopold and Wolman, 1960; Knighton, 1972; Gorycki, 1973). Leopold and Wolman (1960) postulated that this indicates that meander wavelength is (p.769) "determined primarily by the dynamics of flow rather than by relation to debris load" and that (p.776) "sediment alters or affects but does not cause the meander pattern".

There have been some attempts to provide physical explanations for the observed relation between meander wavelength and channel width. For example, Yalin (1977) proposed that meanders may be the result of a horizontal analogue to the vertical eddies responsible for bed forms, and that the scale of the horizontal eddies is controlled by the channel width. Leopold and Wolman (1960) reviewed some of the theoretical work which supports the relation between meander wavelength and channel width and pointed out that the theoretical relations do not agree quantitatively with the empirical relations obtained from the field data.

2.4 Compound Meanders

A number of investigators have described meander patterns which "seem to consist of a meander pattern of low amplitude and wavelength superimposed on a larger pattern" (Schumm, 1963, p. 1090). These are called compound meanders (see Brice, 1974). Compound meanders occur along the Sturgeon River study reach in some locations.

Dury *et al*. (1972) described a channel of reduced discharge which has a new, narrower width, but a planform which relates to the former, larger discharges. Pools, which usually occur only near bends in the meander pattern (see Section 2.7). are also found between bends in channel patterns of this type. The spacing of the pools appears to be adapted to the present discharge regime, that is, to the present channel width.

The Colorado River also has a large meander planform relative to its channel width, and its pool spacing is related to the present channel width (Baker and Penteado, 1975; Looney and Baker, 1977; Baker and Penteado-Orellano, 1977). The changes in the Colorado River are thought to have been brought about by climatic changes which reduced the channel-forming discharge. Similarly, Hjulström (1949) stated that climatic change causing smaller dominant discharges in rivers in Sweden produced meander bends of small wavelength within the old, larger channel patterns. Hjulström postulated that these smaller wavelength bends would, with time, grow larger as the channels adjusted to the new discharge regime.

Narrowing of channel width in order to adjust to a reduced dominant discharge can be achieved quickly under some conditions by deposition of excess load. Also, if the channel is in an environment which permits rapid establishment and growth of vegetation along streams, the plants will encroach upon the channel banks, reducing the channel width (see Section 2.12).

Keller (1972) and Lewin (1972) postulated that the development of compound meanders can be the result of a late stage of meander growth, and not the result of a reduction in the dominant discharge. According to Keller, the process of meandering results in increasing channel length which may lead to the addition of new pools in order to keep the pool-riffle spacing constant. Lewin observed that, with the development of compound meanders, there may be formed, within the larger meander planform, a number of smaller bends associated with the new pools. Lewin and Keller both provided examples in nature of the development of compound meanders.

Another possibility for the genesis of compound meanders is that the smaller meanders are created during low flow conditions and the larger meanders by higher flows, such as the mean annual flood (Hjulström, 1949; Schumm, 1963).

However, the physical significance of compound meanders is poorly understood (Brice, 1973) and these large meander wavelengths may not be hydraulically related to a given discharge or channel width.

2.5 Other Measures of Meander Planform

Along with meander wavelength, several other measures of meander planform are sometimes used in the literature. For example, meander amplitude (Figure 3.4), is also used to characterise meander patterns. Experiments by Friedkin (1945), in uniform sediment at uniform water discharges, produced a meandering channel with a uniform amplitude. Knighton (1972) measured meander amplitudes of streams flowing on reasonably homogeneous material, glacier ice, and found that meander amplitude correlates well with meander wavelength. Jefferson (1902) determined that the limiting width of the meander belt is equal to 18 times the channel width for channels on alluvial floodplains. He considered only "mature meanders", that is to say meanders where meander belt width is between two and three times meander length.

From their analysis, Leopold and Wolman (1960) could find no confirmation that amplitude is a function of either L or W . They concluded that amplitude is controlled by other factors such as the erosional characteristics of the stream banks. In Friedkin's (1945) experiments, amplitude increases with channel discharge, although to a lesser extent as discharge increases. Ackers and Charlton (1970a), using data from laboratory streams in sand, determined that amplitude is a function of Q, water discharge, but the relation shows more scatter than does the relation between meander wavelength and Q. Ackers and Charlton proposed that this may result because the stable meander wavelength is established in the experiments before amplitude achieves a stable size, and because amplitude may depend strongly on factors other than Q.

Another measure of meander geometry is the radius of curvature of the channel bend, Rc (Figure 3.4). The strength of the secondary circulation in a bend is partly a function of Rc (see Section 2.8) and so Rc affects erosion and deposition along the bend. Hickin (1978) found that there is an abrupt reduction in the lateral migration rate of bends when the ratio of Rc to the channel width, W, is less than 2. Leopold and Wolman (1960) found that the relation between meander wavelength, L, and Rc is almost linear. Gorycki (1973) and Leopold and Wolman (1960) have noted that the relations between L, Rc, and W provide consistent correlations through several orders of magnitude. Leopold and Wolman (1960) found that, for natural meandering channels, the ratio of Rc to W is usually between 2 and 3. Knighton (1972) calculated an average value for Rc/W of 1.7 for supraglacial streams. However, Hey (1976) used data from some rivers in England and found much greater variations in this ratio than had been indicated by Leopold and Wolman (1960).

Channel sinuosity is also used to characterise the channel planform. Several measures of sinuosity have been used in the literature (e.g. Mueller, 1968) but the most common is the ratio of channel length to valley axis length (e.g. Schumm, 1963). The sinuosity values so obtained do not always distinguish between very different channel patterns (Smart, 1977). For example, a long wavelength, and high amplitude pattern may have the same sinuosity value as a tortuous pattern with tight bends. Schumm (1963) and Woodyer (1978) found that sinuosity is significantly related to the width to depth ratio of the channel cross-section and to the percent of silt and clay in the channel perimeter.

2.6 Influence of Channel and Valley Slope

It has been recognised in a number of papers that river slope is related to the discharge of the channel (Leopold and Wolman, 1957), the valley slope (Schumm and Khan, 1972; Ackers and Charlton, 1970b), the sinuosity of the stream (Schumm, 1977), and the sediment size (Ikeda, 1970).

Generally, smaller sediment sizes are associated with lower channel slopes and narrower and deeper channel cross-sections. However, as Brush (1961) and Hack (1965) stated, a change in particle size is not necessarily associated with a change in slope. Knighton (1975) found that, for the Bollin-Dean River system, channel slope is well correlated to the bed sediment size, for sediments between 16 and 64 mm, but that almost no change in slope occurs for mean grain diameters of 4 mm or less. Knighton postulated that this is because, for coarse material, channel slope is adjusted to provide the shear stress required to transport the sediment. For finer material, it may be that channel depth, rather than channel slope is modified to provide the shear stress required for erosion and transportation of the sediment.

Channel pattern has been shown by several investigators to be related to the slope of the channel and of the valley. Channel slope-discharge relations determined by Leopold and Wolman (1957) and Lane (1957) divide braided channels from meandering channels. Note that Lane's equations use mean discharge, while Leopold and Wolman's use bankfull discharge. Lane also observed that there are indications that, at much lower slopes than are represented by his equation for meandering streams, the channel pattern becomes very tortuous and at extremely low slopes, the streams tend to be straight.

Ackers and Charlton (1970b) concluded that, for their laboratory streams, there appears to be a threshold valley slope between straight channels at lower slopes and meandering channels at higher slopes. Schumm and Khan (1971, 1972) discovered that, for laboratory streams, as valley slope increased, there exist two thresholds where abrupt changes in channel pattern take place, (Figure 2.1). A natural example of this is the pattern of the Guadalupe River which changes from tortuous to straight with decreasing slope (Morton and Donaldson, 1978).

Table 2.1 lists some of the equations given in the literature which express relationships between slope, discharge, and channel pattern, and also provides information as to the type of sediment for which these relations were derived. To generalise, as the stream power, either through slope or discharge, increases, the channel first increases its sinuosity. With further increases in stream power, the channel decreases its sinuosity and eventually becomes braided (Schumm and Khan, 1972; Ferguson, 1973; Leopold and Wolman, 1957).

At which slope and discharge the transitions in channel pattern occur depends partly on bank erodibility. For example, if the sediments are easily erodible then the transition to braiding may take place at a lower stream power than if the sediments are more difficult to erode. Henderson (1961) showed that the relationship between slope and discharge is dependent on sediment size for sand and coarser particles. For Alberta rivers (Figure 2.2), sand-bed channels plot below gravel-bed channels on the slope-discharge graph.

Several investigators noted that the slope - discharge - planform relations do not apply to channels which have

Figure 2.1 The relationship between sinuosity and valley slope from laboratory stream experiments (Schumm and Khan, 1972, p. 1761, Figure 6).

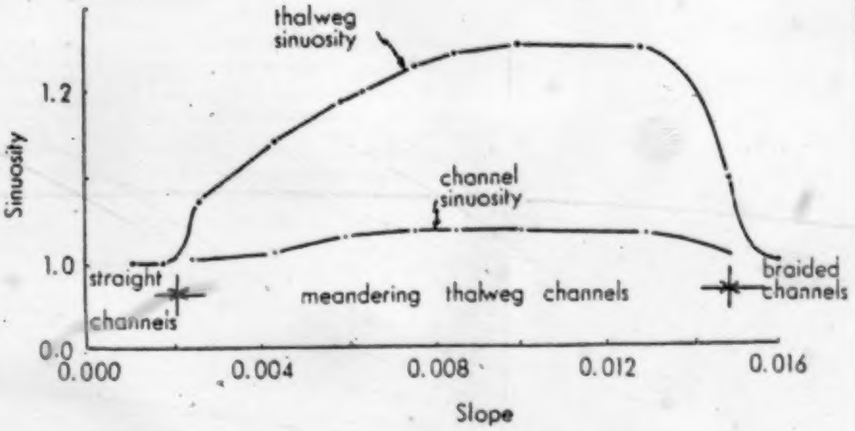


TABLE 2.1. Slope-discharge relationships from the literature. The channel slope is Sc; the valley slope is Sv; discharge is Q; bankfull discharge is Qb; mean discharge is Qm. Where necessary, the equations have been converted from discharge in cusecs to discharge in cumecs.

A. Ackers-Charlton - from Ackers and Charlton (1970a) and revised by Ackers (1980), for dividing straight from meandering planforms.

(i)	$Sv = 0.0008\ Qb^{-0.21}$	For laboratory and natural sand bed channels. When Sv is greater than this, the channel meanders.
(ii)	$Sc = 0.0014\ Q^{-0.12}$	For laboratory channels in fine sand. When Sc is greater than this, the channel meanders.

B. Leopold-Wolman - from Leopold and Wolman (1957), for dividing meandering from braided channels, for natural streams with the median size for bed material ranging from coarse sand to cobbles.

(iii)	$Sc = 0.013\ Qb^{-0.44}$	When Sc is greater than this, the pattern is braided.

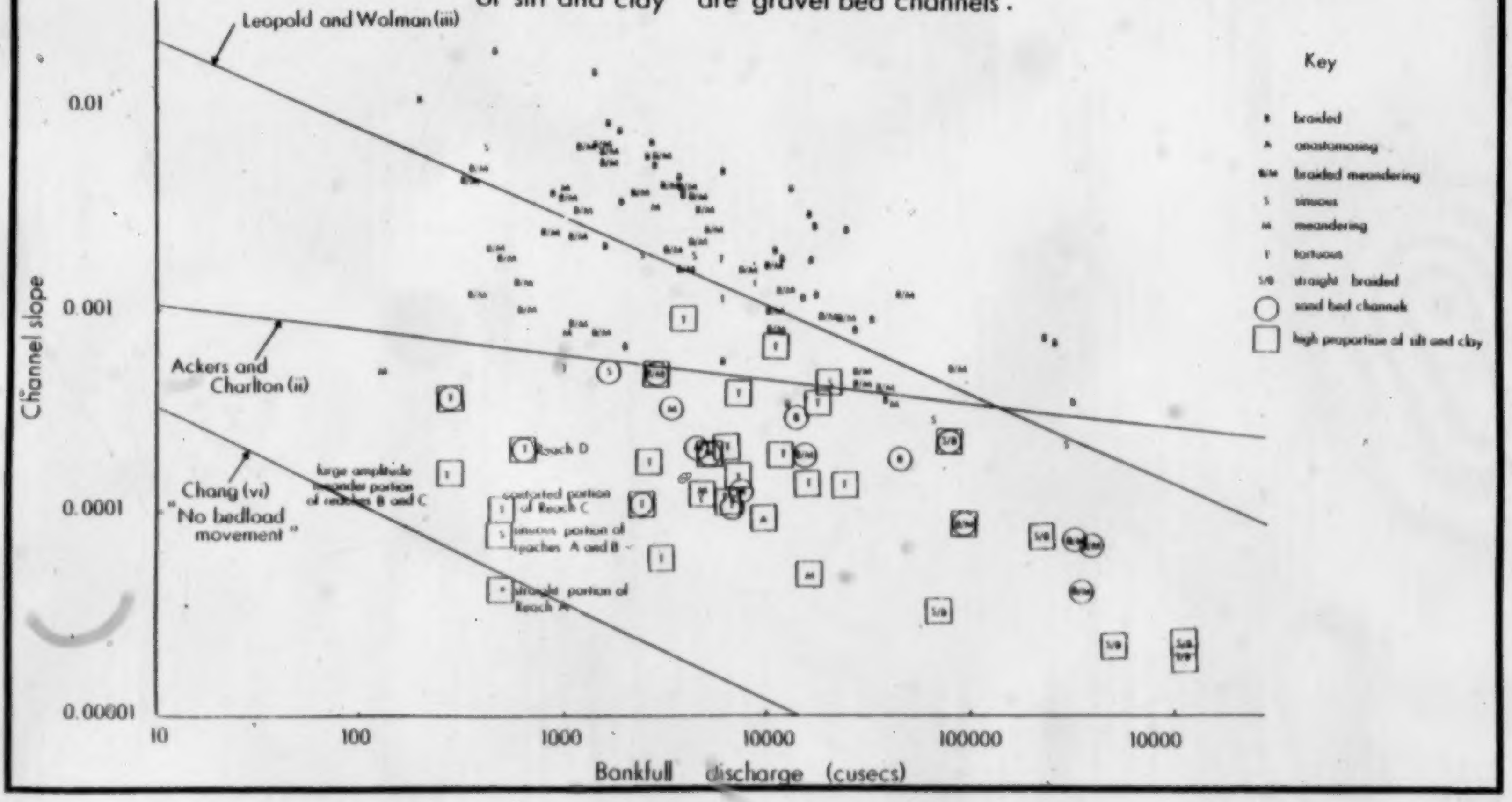
C. Lane - from Lane (1957), for natural and laboratory sand bed streams.

(iv)	$Sc = 0.0041\ Qm^{-0.25}$	Describes braided channels.
(v)	$Sc = 0.0007\ Qm^{-0.25}$	Describes meandering channels.

D. Chang - from Chang (1979), for sand bed streams, derived from a theoretical basis.

(vi)	$Sc = 0.00018\ Qb^{-0.48}$		No bedload movement.
(vii)	$Sv = 0.00017\ Qb^{-0.433}$		No bedload movement.
		(vii)<Sv<(viii)	Straight-unbraided.
(viii)	$Sv = 0.004\ Qb^{-0.523}$	(viii)<Sv<(ix)	Straight-braided.
(ix)	$Sv = 0.0043\ Qb^{-0.486}$	(ix)<Sv<(x)	Transition from straight-braided to meandering.
(x)	$Sv = 0.0045\ Qb^{-0.42}$	(x)<Sv	From meandering to steep braided.

Figure 22 Channel slope vs. bankfull discharge for Albérta Rivers (Kellerhals *et al.*, 1972) and for channels with a high proportion of silt and clay in the channel perimeter. All data points which are not marked as either "sand bed channels" or "high proportion of silt and clay" are gravel bed channels.



cohesive channel perimeters. Lane (1957) found that the Red River, a meandering river which has cohesive bank material, has a much lower slope than the slope yielded by his empirical relationship for meandering rivers. Chang (1979) found that some sinuous channels plotted in the "straight" region of his graph, and postulated that (p. 323) "Possible reasons for this inconsistency are finer bed materials and steeper side slopes than those used in constructing the diagram." Riley (1975) studied the Namoi-Gwydir distributary system in which the channel banks and freqently the channel beds are cohesive. These channels are highly sinuous and yet some of the data points plot in the "straight" region of the Ackers-Charlton relationship. Riley postulated that this may be because the channels in the Namoi-Gwydir system are not "live-bedded" and so the Ackers-Charlton relationship is not applicable. Taylor and Woodyer (1978) studied the Barwon-Darling River, which is part of the Namoi-Gwydir system and which has a very low slope and a highly sinuous channel planform. Although much of this channel is live-bedded (i.e. has transport of sandy bed material) the banks have been stabilised by clay. Taylor and Woodyer conclude that, for the Ackers-Charlton relationship to apply, channels must have both live beds and live banks.

The data shown in Table 2.2 are for channels in which part or all of the channel perimeter is composed of fine cohesive material, and the bed material is not coarser than sand. No authors provided valley slope data, although it has

TABLE 2.2. Data from the literature for channels with cohesive material in the channel perimeter.

River	Source	Planform	Sinuosity	Channel slope	Valley slope^1	Mean discharge (m^3/s)	Bankfull discharge (m^3/s)	Channel perimeter sediments
Namoi-Gwydir system	Riley (1975)	Tortuous	N/S^2	0.00036	N/S	85	520	silt & clay; silt & clay banks with sand bed
			"	0.00056	"	51	304	
			"	0.00006	"	9	87	
			"	0.000125	"	17	133	
			"	0.00039	"	31	203	
			"	0.00015	"	31	203	
			"	0.000119	"	23	174	
			"	0.00091	"	11	107	
			"	0.00018	"	6	75	
Illinois	Lane (1957)	Straight-braided	N/S	0.00003	N/S	425	1982	sand bed (Lane); silt bed, silt & clay banks (Rubey, 1952)
Red River	Lane (1957)	Meandering	N/S	(a) 0.000127	N/S	13	136	cohesive banks; some fine sand on bed
			"	(b) 0.000049	"	62	453	
St Clair	Lane (1957)	Straight-braided	N/S	0.000023	N/S	5352	14158	some cohesive material; sand bed
Nile	Lane (1957)	Straight-braided	N/S	0.000078	N/S	2554	6230	clay banks sand bed
Nooksack	Lane (1957)	Straight	N/S	0.00045	N/S	93	566	"fine"
Yangtze	Lane (1957)	Straight-braided	N/S	(a) 0.000023	N/S	25485	31149	sand bed; some cohesive material
			"	(b) 0.00002	"	"	"	
Verdigris	Lane (1957)	Meandering	N/S	0.000138	N/S	116	680	sand bed; some cohesive material
Assiniboine	Lane (1957)	Tortuous	N/S	0.0002	N/S	47	340	on Glacial Lake Agassiz Plain
Minnesota	Lane (1957)	Tortuous	N/S	0.00014	N/S	61	453	former outlet of G.L. Agassiz
Athabasca below McMurray	Kellerhals *et al.* (1972)	Straight with some islands; entrenched	1	0.00023	0.0023	646	2210	sand bed with local gravel, clay &silt; erodible rock
Athabasca at Embarras Airport	Kellerhals *et al.* (1972)	Irregular meanders with islands occasionally confined	1.35	0.00009	0.00012	767	2605	silt & sand clay & silt banks; sand bed

TABLE 2.2. continued:

River	Source	Planform	Sinuosity	Channel slope	Valley slope	Mean discharge (m^3/s)	Bankfull discharge (m^3/s)	Channel perimeter sediments
East Prairie	Kellerhals et al. (1972)	Irregular with islands; tortuous meanders upstream, swamp downstream	1.4	0.0005	0.0007	6.5	79	silt & sand or clay & silt banks; sand bed
Swan	Kellerhals et al. (1972)	Tortuous meanders, mid-reach straighter	1.7	0.0002	0.00034	13	149	clay & silt banks; sand bed
Vermillion	Kellerhals et al. (1972)	Tortuous meanders	2.2	0.00037	0.000814	1.4	[illegible]	silt & sand, mod. erodible rock banks; silt & sand bed
Lesser Slave	Kellerhals et al. (1972)	Contorted meanders	2.0	0.00011	0.00022	44	69	silt & sand banks; sand or silt bed
Pembina at Jarvie	Kellerhals et al. (1972)	Irregular meanders with point bars	2.0	0.00011	0.00022	41	190	silt & sand banks; sand with local gravel over clay bed
Upper Columbia	Smith (pers. comm. 1980)	Anastomosing	1.16	0.000096 (maximum)	0.000096	37	271[3]	sand bed, fine banks

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1 valley slope = channel slope x sinuosity for the Kellerhals et al. data

2 N/S - not specified

3 Combined discharges of the four channels of the anastomosed river

been calculated here where both channel slope and sinuosity values were given. Because very few data points were available, also included are tortuous channels from Lane (1957) which have sandy beds and which may have silty or silty-clay banks, perhaps glacio-lacustrine sediments: the Assiniboine and Minnesota rivers.

The data are of variable comparability. Riley (1975) did not specify which channels have perimeters entirely of silt and clay and which have perimeters partly composed of sand. Smith's (1980, pers. comm.)and Riley's bankfull discharge values have been converted to mean annual discharges and Lane's mean annual discharges have been converted to bankfull values using Chang's (1979, Figure 13) relationship. Note that Chang states that much scatter occurs at lower discharges (i.e. from about 0.3 cumecs to 28 cumecs) for his bankfull-mean discharge relationship. The bankfull discharge used for the Kellerhals *et al*. (1972) data is the two-year flood. Although Kellerhals *et al*. provide bankfull values for some reaches, most of the values are relatively large i.e. greater than the five-year flood (see Kellerhals and Church, 1980). The two-year flood discharge was selected on the basis of evidence from Bray (1972) which indicates that some bed material movement occurred at this discharge frequency, that is it may be the channel-forming discharge.

The channel pattern descriptions given in Table 2.2 are from the source of the data except for the Yangtze, St.

Clair, Nile and Illinois rivers. Lane described these stream as "braided" in his Table I and "straight" in the text of his article. These channels appear to correspond to Chang's "straight-braided" classification. They occur on very low slopes and are almost straight but have occasional islands which, in some cases, seem to occur at regular intervals.

Generally, most of the data points occur in the middle range of discharges. The scatter on Figures 2.3 and 2.4 may be attributed, in part, to the variation in the accuracies of the bankfull values and the slope values and perhaps because of the varying proportions of silt and clay in the channel perimeters of the different channels

All the data points occur at relatively low slopes and there does not appear to be any trend towards a change in channel pattern with a change in slope. There may be a change from tortuous to braided-meandering, braided or straight-braided with increasing discharge. However, with so few data points, it is difficult to know if this is an actual trend or only the result of the small sample size.

These channels plot within the same region of Figures 2.2, 2.3, and 2.4 as the sand-bed channels and, in fact, most of these channels do have sand beds. Many of the streams plot below the channel pattern relations established by Lane for sand-bed channels. All of the streams plot above Chang's "no bedload movement" line except the upper part of Reach A ('straight portion') of the Sturgeon River. For small discharges the channel pattern changes greatly with a

Figure 2.3 Valley slope vs. bankfull discharge for channels with a high proportion of silt and clay in the channel perimeter (see Key on Figure 2.2).

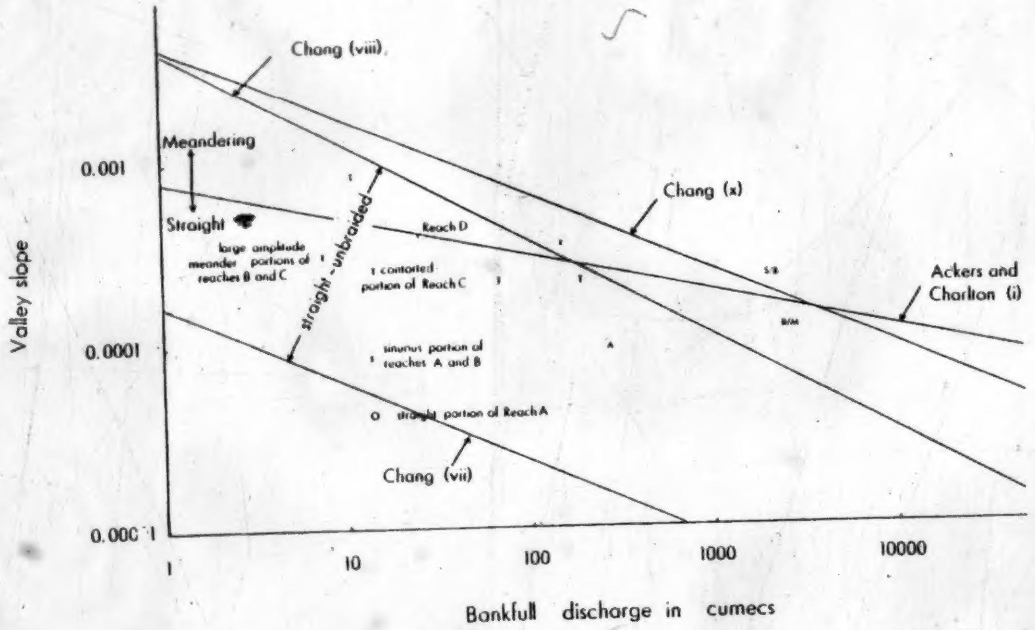
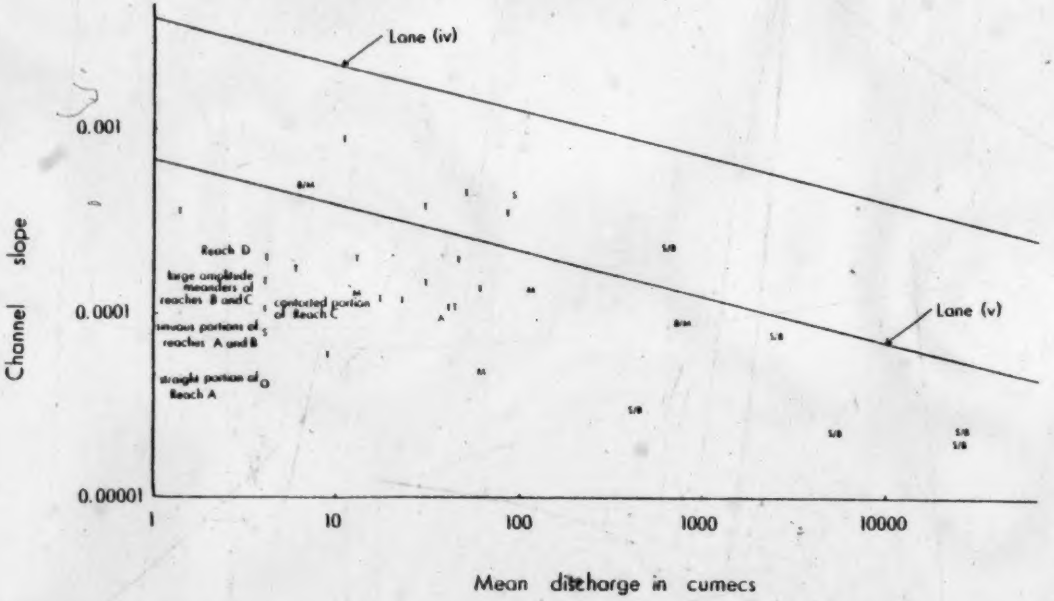


Figure 2.4 Channel slope vs. mean discharge for channels with a high proportion of silt and clay in the channel perimeter (see Key on Figure 2.2).



small change in slope according to Chang. There are very few points with valley slope data. However, the locations of these few points do not correspond with either Chang's or the Ackers-Charlton relationship.

Consequently, although there may or may not be slope-discharge thresholds for pattern change in channels with cohesive channel perimeters, the values obtained for channels in sand and gravel do not apply to channels with cohesive materials, according to the available data.

2.7 Channel Cross-sectional Form

The size of a stream cross-section is predominantly a function of the magnitude of the dominant discharge (Leopold, Wolman, and Miller, 1964). There has been some work which suggests that it may also be affected by the channel planform (Ackers and Charlton, 1970a; Schumm and Khan, 1972). However, the nature of the relation is unclear.

A channel of semicircular cross-section has the largest possible hydraulic radius, and water will flow fastest in a channel of this shape (Rubey, 1952). However, if the channel has erodible walls, it will not be able to maintain a semicircular cross-section. Thus, natural channels have widths which are much greater than their depths.

Usually associated with a meander pattern are "pools", or "deeps", at the bends in the planform, and "riffles", or "shallows", at the inflection points of the meander pattern.

Typically, the riffles have a trapezoidal cross-sectional shape. The maximum depths in pools are usually skewed towards the outside of the bends (Friedkin, 1945). Often pools are located just downstream of the apex of the meander bend but may be just upstream of the apex or almost at the cross-over (Leopold and Wolman, 1960). As discussed above, pools also may occur between bends as well as at bends (see Section 2.4).

Laboratory studies indicate that pool development is an integral part of meandering in sand bed streams. Ackers and Charlton (1970a) observed that shoals and deeps begin to form along the channel at alternate sides of the channel. Initially, the channel remains straight while the shoals migrate downstream. Then "almost simultaneously" (p. 259), embayments are eroded in the the banks beside the deeps, and a meandering planform is developed. Schumm and Khan (1972) showed that a relatively straight laboratory channel with a pattern of alternating shoals develops into a truly meandering planform only when the shoals are stabilised by the deposition of clay, which had been added to the flow as suspended load.

In the above two studies, the development of pools occurs before the meandering planform is produced. The pools and shoals of the straight pattern develop into the pools and point bars of the meandering pattern. Thus, these experiments seem to indicate that, for a meandering planform to develop in sand bed channels, initially there must be a pattern of alternating shallows and deeps. It is important to note that the occurrence of pools and shoals is not characteristic of all meandering channels. Prus-Chacinski (1971) observed that shoals do not occur in some clay and silt bed channels.

2.8 Flow in Bends

Once a bend in the planform develops, the main flow of the water follows a curved path around the bend. A pressure gradient is set up across the channel as the centrifugal force causes the water particles to move towards the outside of the bend. The water surface is higher along the outside of the bend as compared to the inside of the bend and so the pressure is greater along the outside of the bend. The bottom layers of water are slowed by friction with the bed to a greater degree than the upper layers of water. Centrifugal force is a function of the mass of the water and the square of the velocity of the flow, and inversely related to the radius of curvature of the bend. Thus, the centrifugal force is least on the water near the bed because of its relatively slow velocity. The retarded water along the bed tends to flow towards and up the inside of the bend, where the pressure is lowest, and the upper layers of water along the outside of the bend tend to flow downward along the bank. Thus, a secondary helicoidal flow is set up in the bend. There is erosion along the outside bank by the downward flowing water and deposition along the inside bank by the rising water. For more detailed discussions of helical flow in bends, see Thomson (1876), Prus-Chacinski (1958), and Leopold and Wolman (1960).

2.9 Channelisation

Channel readjustments to artificial straightening and removal of pool and riffle sequences have been described in several papers. Ferguson (1973, p. 38) stated that adjustment to man-induced channel pattern changes "seem to require only tens or hundreds of years" and that "bed slope is much more readily adjusted via sinuosity than by aggradation or incision". However, neither of these observations is strongly supported by other studies. In fact, headward erosion, and downstream deposition are common results after channelisation (Daniels, 1960; Emerson, 1971; Yearke, 1971; and Morisawa, 1974). Some investigators observed that, initially, these adjustments occur rapidly but, with time, the rate of change declines (Daniels, 1960; Yearke, 1971). In some cases, the straightened streams are able to create new pool and riffle sequences (Keller, 1975, 1978; Morisawa, 1975). It is not clear from the literature if these channels are able to return to a meandering planform or only to a meandering thalweg. Sometimes the readjustment to form a meandering thalweg is rapid (Morisawa, 1974; Keller, 1978) but in other cases, the pool and riffle sequences are only poorly developed and unstable even after many years (Keller, 1975, 1978). Emerson (1971) cited an example wherein a river was channelised 60 years previous to his observations, but was still entrenching, and showed no sign of returning to a meandering planform. Noble and Palmquist (1968) found that the cross-sectional form of some straightened channels eventually came to equilibrium with the bank sediment type, but that even after 70 to 80 years, meander wavelength and amplitude were not correlated with the percent of silt and clay in the banks. Keller (1978) postulated that if a straightened channel remains below a threshold slope, then the channel will be able to reform pool and riffle sequences.

2.10 Influence of Channel Perimeter Sediment and Sediment Load

Streams are able to meander in a variety of media (Tanner, 1960; Leopold and Wolman, 1960; Zeller, 1967). The relationships between meander wavelength, and channel width, and between radius of curvature and channel width are similar, despite different media (Leopold and Wolman, 1960; Gorycki, 1973). According to Leopold and Wolman (1960, p. 769), this implies that meander shape is "determined primarily by the dynamics of flow rather than by the relation to debris load". However, other studies have indicated that, for alluvial rivers, sediment transport and friction are necessary to the development of meandering (e.g. Parker, 1976).

The amount of sediment load has been shown to be important. Griggs (1906) performed some simple experiments in order to investigate the effect of load on channels. A small swift stream was forced to follow a meandering planform. At a point about halfway along the stream's course, sand was added as fast as it could be carried away. In the lower portion of the channel, point bars developed and concave banks were eroded. The lightly-loaded upper half of the channel became straighter than the originally imposed pattern. Friedkin (1945) found that only one rate of sand feeding will maintain a given channel cross-section and slope. If there is less load than required, the channel deepens and flattens; if there is more than required, aggradation occurs at the upper end of the channel and the slope steepens.

Also important is the type of load which the channel is transporting. As discussed above, in laboratory experiments by Schumm and Khan (1971, 1972), the planform of the streams becomes truly meandering, as compared to a meandering thalweg within a straight pattern, only when suspended load is introduced into the channel and the bed load fed into the channel is reduced. Schumm and Khan postulated that the clay stabilises the alternate bars of the meandering thalweg. This causes scour and deepening of the thalweg, permitting the alternate bars to emerge to form point bars and sinuosity to increase. Another result of the addition of suspended load to Schumm's and Khan's laboratory streams is an increase in channel depth, a decrease in width and an overall decrease in cross-sectional area.

Field data on the effect of fine sediments on river channel geometry have been studied by Schumm in several publications (1960a,b, 1961a,b, 1963). Although there has been some criticism of Schumm's mathematical analysis (Melton, 1961; Miller and Onesti, 1979), there is general agreement that the proportion of fine sediment in the channel perimeter is at least weakly related to the channel geometry (Ferguson, 1973; Morton and Donaldson, 1978; Miller and Onesti, 1979). Fine particles like silt and clay are usually transported as suspended load, while coarser particles are carried as tractive load. The clay fraction of the sediment acts to decrease the permeability of the channel perimeter and to increase the cohesiveness and thus to increase the resistance to erosion of the channel perimeter.

Schumm determined that W/D, the channel width to channel depth ratio, is significantly related to M, a weighted silt-clay factor. M is weighted in order to represent the percent of silt and clay in the entire channel perimeter. Melton (1961) criticised Schumm's analysis primarily because M includes channel width and channel depth. Thus, according to Melton, W/D and M are mathematically related, creating a falsely high degree of correlation. Ferguson (1973) reanalysed Schumm's data and found that the per cent silt-clay in the banks is only weakly related to channel width. Miller and Onesti (1979) also reanalysed Schumm's data. They determined that there is a significant (at the 99% level of significance) relationship between W/D and and the percent silt-clay in the banks and a very poor relationship between W/D and the percent silt-clay in the channel bed and between W/D and the median grain size.

Leopold and Maddock (1953) found, from regression analysis, that a river carrying a large proportion of bed load usually has a wide, shallow channel, while a river carrying a high proportion of suspended load has a deep, narrow channel. Wolman and Brush (1961) using flume data and some field data, determined that channel cross-sectional shape is a function of the angle of repose of the bank material and the force required to move the material.

Local variability in sediment type can also be important. Friedkin (1945) showed that in uniformly erodible sandy sediment, uniform meanders are formed and the whole meander pattern tends to migrate uniformly downstream without forming cutoffs. In bank material of uneven erodibility, the meander shape varies from low amplitude curves to sharp bends. Cut-offs can form if erosion on the downstream arm of the bends is relatively slow as compared to that on the upstream arm due to more resistant material in the downstream arm. Locally resistant banks have been observed by Carey (1969) to generate sharp-angled bends. When the stream impinges upon these relatively inerodible banks, a large eddy may form upstream, causing a local widening of the channel.

For alluvial rivers on the Great Plains, narrow and deep rivers with a high percent of silt and clay in their perimeters usually have higher sinuosities, while wide, shallow channels with coarser sediments are of low sinuosity (Schumm, 1963). Schumm (1967) showed that meandering rivers transporting high proportions of sand and gravel have larger meander wavelengths than meandering rivers of similar discharge but transporting predominantly fine sediments. Studies on the past and present regimes of the Colorado River (Baker and Penteado, 1975; Looney and Baker, 1977) indicate that the low sinuosity phases of the river were gravel-transporting, wide channels. Higher sinuosity phases carried sand and silt, and had narrower channels. Phases with maximum sinuosity had significant quantities of silt and clay in their deposits.

2.11 Channels with Low Slopes and Fine Sediments

Several authors have investigated streams with very low valley slopes, and banks with high proportions of fine sediment. Griggs (1906) described the Buffalo River, the lower reach of which flows on the Glacial Lake Agassiz Plain. This portion of the river has a low slope, clay banks and very turbid waters. It is extremely crooked in planform, its bends are relatively stationary and cut-offs are rare, and the river appears to be cutting both banks in many places. Lane (1957) discussed the Red River which also flows through Glacial Lake Agassiz sediments. The Red River has a low slope, high sinuosity and few cut-offs. The banks are of clay loam and the water in the river is very turbid. Lane believed that the slow migration of the river is due to the low channel slope which limits the ability of the stream to attack its banks. Welch (1973) observed for the Red River in the Winnipeg area, that active erosion is occurring on the inside banks of bends, while the outside banks appear to be relatively stable. He did not propose that this was characteristic of low slope - suspended load streams. Instead, he postulated that it was due to channel straightening.

Rubey (1952) observed that the Illinois River carries a fine sediment load, has banks of clayey-silt, and narrow channel cross-sections. It was not actively eroding its banks and had not shifted laterally for many years at the time Rubey studied it. It has no scroll bars (see Table 4.4) on its floodplain, although there are levees along its banks. It has a very low channel slope caused by low valley slope rather than channel sinuosity.

Woodyer *et al.*(1979) studied a reach along the Barwon River, a very low gradient stream carrying predominantly suspended load. The channel is narrow and deep, the average width to depth ratio being 8. It has a relatively high sinuosity of 2.3. Most of the suspended load is clay and the bed material is variable in mean sediment size, ranging from sand to clay. The Barwon River has not shifted position significantly since at least 1848, although there is local bank erosion on the outside banks of bends in some places. There is no ridge and swale topography associated with the current phase of the river. The active floodplain is (p. 117) "a narrow and discontinuous surface within the stream channel". These within-channel benches are deposited along the banks of the stream, the higher benches being flooded about once per year. Woodyer *et al.* proposed that constriction of the channel by these benches may be one cause of channel avulsion.

Generalising, channels with low valley slopes and perimeters of predominantly silt and clay, usually transport a large proportion of suspended load and are often tortuous in planform. They are usually characterised by narrow, deep cross-sections. They appear to migrate only very slowly and lack the ridge and swale topography which often characterises more rapidly migrating meandering channels.

2.12 Effects of Riparian and Aquatic Vegetation

The vegetation along the channel, riparian vegetation, and in the channel, aquatic vegetation, may affect the channel morphology. Maddock (1972) described some of the effects of vegetation along the river banks. It increases bank resistance to erosion by binding the bank sediment with plant roots. It encourages deposition of sediments by lowering the velocity of the water when it encounters the vegetation. Riparian vegetation encroaches upon the channel bed at low flow, reducing the effective width of the channel. Many qualitative observations have been made concerning the effect of riparian vegetation, although few quantitative investigations have been made (e.g. Burkham, 1972; Smith, 1976).

If riparian vegetation established at low flow grows large and strong enough to withstand higher flows, the channel width will be reduced and the channel depth may be increased as erosion is concentrated on the bottom of the channel (Maddock, 1972; Hadley, 1961; Smith, 1976; Burkham, 1972). During very high flows, if the river cannot widen itself because of the effects of the riparian vegetation, much of the flood waters may be forced over the banks and/or the channel may cut downward (Smith, 1976). If the vegetation has deep roots which protect the banks against erosion, and if it has time enough between major floods to secure itself, the channel may be very slow to migrate (Leopold and Wolman, 1957). Schumm and Lichty (1961) and Nevins (1969) described changes from wide, shallow channels to narrower, meandering channels with the growth of stabilising bank vegetation.

Aquatic vegetation, like riparian vegetation, stabilises channel perimeter sediments, slows the water velocity which encourages sediment deposition, physically traps debris around which sediments can accumulate, and reduces channel cross-sectional area (Stephens *et al.*, 1963; Guscio *et al.*, 1965; Gaudet, 1974).

According to Gaudet (1974), emergent aquatic plants, those which have only their lower portions submersed (Klots, 1966), are the most effective at trapping silt. If the water current becomes strong enough, submersed aquatic plants, those which are entirely submersed (Klots, 1966), will be depressed and no longer able to reduce the velocity as effectively. Nevertheless, if submersed water plants occur in thick mats, their effect can be important (Stephens *et al.*, 1963).

Vegetation acts to modify sediment and flow conditions in channels. There is some debate in the literature as to whether it is an active or passive agent (Everitt, 1979; Graf, 1979). Its main effect may be the augmentation of channel characteristics already present, by increasing deposition on and stabilising slow-moving and/or shallow areas in the channel.

2.13 Conclusions

Meander wavelength, amplitude, radius of curvature and sinuosity have all been used in the literature to characterise meander shape in order to calculate simple relations between meander planform and other relevant variables. Variations in cross-sectional form, channel and valley slope, sediment, water discharge, and vegetation are all interrelated with variations in channel planform. However, the changes and adjustments which a river makes are often quite complex, especially along natural rivers where many characteristics may vary to different degrees along a given reach.

3. TECHNIQUES OF DATA COLLECTION AND ANALYSIS

3.1 Introduction

In this chapter, the techniques for field data collection, laboratory analysis, and mathematical analysis are described along with the problems involved. The techniques discussed are cross-sectional measurement, sediment sampling, laboratory sediment size analysis, mathematical analysis of the sediment data, planform and slope measurement, and mathematical analysis of the relations between the variables under consideration.

3.2 Channel Cross-sectional Data

The cross-sectional data for Reach A are from Szabon (1975) and Yaremko (1968). All the other channel cross-sections were measured at two different times by me. Initially, the entire cross-section was to be measured when ice covered the channel. However, difficulties in drilling through the thick ice cover prevented this. Therefore, during the winter, the ice surface widths and the cross-sections above the ice level were measured. The next summer, the cross-sections below the water surface were measured. These two portions were then fitted together.

3.2.1 Field Measurement of Cross-sections

The above-ice-level cross-sections were measured using a self-levelling Wild level and a stadia rod. Because there was snow along the channel banks in some places, the channel edge was sometimes difficult to define precisely. Thus, the channel widths may be slightly too large or too small. Reeds and small bars also obscured the channel edge. The magnitude of the error in defining the banks is not known.

To measure the below-water cross-sections, a calibrated rope was stretched across the channel for width measurements and a calibrated pole was used to measure depths. Depths were measured at approximately metre intervals whatever the total channel width. The pole had a small platform on the bottom to keep the pole resting on the bed surface, rather than penetrating into loosely compacted river muds.

This method was simple, and required only a single person, but was not very accurate. The rope was calibrated when dry and it stretched slightly when wet, making the measured width values smaller than the actual widths. Also, when the river current was strong, the line of the rope across the channel became slightly curved, causing the measured widths to be greater than the actual widths. There was no way to ascertain if the pole was exactly vertical and so the measured depths may be slightly greater than the actual depths.

Unfortunately, there was never a comparison made of the rope-pole measurements with more accurate surveying methods.

The depth errors are likely greater when the channel is relatively deep because, with only a short length of pole above water, it becomes difficult to judge whether or not the pole is near vertical. Similarly, the wider the channel and the faster the current, the greater the errors in width measurement.

In reaches B and C, wide areas of reeds are found along the channel margins. It was extremely difficult to go through these reeds. It was also extremely difficult to find exactly where the water's edge occurred because the slope of the banks was very gentle and the ground surface was irregular. Thus, for convenience, the boundary of the emergent aquatic plants along the channel was used as the edge of the channel for measurement purposes. There is some justification for using the reeds as the channel boundary. At the time of measurement, the reeds interfered with the water flow, so that the water was generally stagnant around them. Therefore, the portion of the channel in which most of the water flows was that beyond the reeds. It is obvious, however, that the reeds are subject to natural variations and that the "reed boundary" is not a continuous line. Furthermore, the submersed aquatic plants also appreciably reduced flow velocities along the channel margins but the decision was made to use the emergent aquatic plants for the boundary since their boundary was generally easier to delimit.

3.2.2 Fitting the Cross-sections

One major problem in fitting the above-ice-level cross-sections to the below-water-level cross-sections is that the ice levels and the water levels do not represent exactly the same discharges. It was assumed that the discharges were approximately the same. The above-ice-level cross-sections were measured between November and December in 1978. The last discharge measurements in 1978 were 2.57 cumecs at the gauge near Fort Saskatchewan and 2.06 cumecs at the St Albert gauge. Both measurements were taken on November 2. Freeze-up took place shortly after this, in mid-November, for the reaches near St Albert. The faster flowing water in gravel bed reaches further downstream probably froze at slightly later dates. There was some precipitation between November 2 and the mid-November freeze-up. Therefore the discharges may have been slightly higher at freeze-up. The below-water-level cross-sections were surveyed at discharges between 1.72 cumecs and 3.10 cumecs. Thus, the stages of the two sets of cross-sectional data should be roughly comparable.

Another problem in fitting the data is that there are errors in both the above-ice-level and below-water-level cross-sectional data, and the magnitudes of these errors are not known.

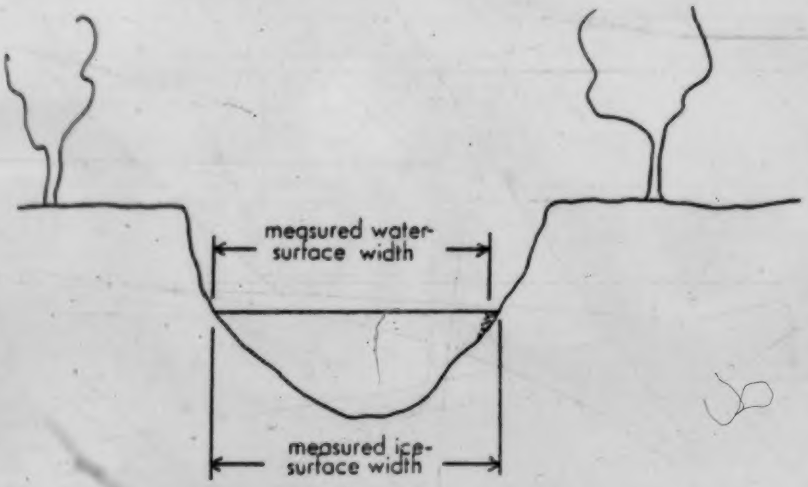
In Reach E particularly, the exact locations of some of the cross-sections were difficult to reestablish in order to make the second set of measurements. In most other reaches, some object, such as a fence post, could be used as a marker of the cross-sectional location, but Reach E was predominantly forested.

For some reaches, the fit of the two parts of cross-sections was relatively easy. That is, when the water surface widths fitted almost exactly with the ice surface widths, no adjustments were made. In other reaches, there was a marked difference between the two measured widths. In these cases, the process of fitting together the two portions was rather subjective. As discussed above, errors were possible in measurements of both types of cross-sections.

The two parts of each cross-section were placed together so that approximately the same bank slope was maintained above and below water for steep banks. For gently sloping banks, it was assumed that the bank slope did not change greatly from the above-ice bank slope to the below-water bank slope. Where the above-ice and below-water bank slopes did not match well, both were adjusted to fit an averaged slope value.

For Reach B and much of Reach C, the above-ice and below-water cross-sections fitted together without any adjustments. The narrow, deep cross-sections at the downstream end of Reach C required more adjustment, probably in part because of the occurrence of small bars along the channel sides (Figure 3.1). The problems caused by bars along the channel margins also apply to some cross-sections

Figure 3.1 Comparison of measured ice-surface width with measured water-surface width when small bars occur along the channel margin.



in reaches D, E, and F.

The worst fitting cross-sections were for Reach E. The above-ice cross-sections were surveyed when the snow cover was greatest. Also, as noted above, it was difficult to identify exactly cross-section locations when the below-water form was measured the following summer.

Occasionally, the above-ice cross-sections did not have an exactly level ice surface. The average difference between the elevations of the left and right side of the channel was 4 cm over a 15 m width. Part of this may be measurement error in reading the level. It was assumed that most of the difference was caused by a small bar, that is the elevation of the bar, not of the ice surface was measured. In all cases, this assumption is in agreement with the below-water cross-sectional information.

The "observed" channel width referred to here is the fitted water/ice surface width. Observed channel mean depth is the average of all the measured depths from the water/ice surface width. Observed channel maximum depth is the maximum measured distance below the water/ice surface. Observed channel cross-sectional area was calculated using a computer program to sum the areas of the trapezoids which are formed by the width and depth data.

3.2.3 Bankfull Cross-sections

There has been much discussion in the literature relating to which discharge or combination of discharges is the dominant discharge (see Section 2.3). Frequently, the "bankfull" values are selected for use in analysis of channel characteristics, "bankfull" being "a flow which just fills the channel to the tops of the banks", (Williams, 1978, p.1141). If it is decided to use bankfull data in the analysis, then the problem becomes how to define "bankfull". Although the concept of bankfull is relatively simple, it is sometimes difficult to apply in practice. For a critical discussion of the various measures of bankfull stage and bankfull discharge, see Williams (1978). In terms of the present study, there were numerous difficulties in determining which stage and discharge should be used as a measure of bankfull in order to permit comparison with relationships between the bankfull hydraulic geometry values, and channel pattern or sedimentary characteristics found for the Sturgeon River with those found in the literature, as well as for comparison between different parts of individual Sturgeon River reaches.

Putting aside the problems involved with the following methods (Riley, 1972; Williams, 1978), grain size or vegetation changes as markers of the bankfull stage could not be utilised here because the elevations of these characteristics were not measured. In some reaches there did not appear to be a consistent downstream vegetation or sediment change with elevation above the river bed. Also, many of the reaches were surveyed when snow was covering these features.

There were problems in utilising hydraulic geometry relations, for example, those of Wolman (1955). In these relations, width, area or width:depth is plotted against stage, and the stage which is associated with the break in the slope on these plots is named as the "bankfull" stage. For the Sturgeon River, the breaks in the slopes occur at stages which represent markedly different discharges in different portions of individual reaches. Therefore, it is difficult to compare the characteristics along a given reach in some cases. Furthermore, it is not known which discharge values these different stages represent. Also, in some reaches, the breaks in slopes occur near the 1 in 80 year flood stage, and in some places, the breaks in slopes occur at discharges lower than the mean discharge. These unusually low and unusually high recurrence intervals may not be comparable to bankfull relations given in the literature. The very low recurrence intervals are probably not hydraulically meaningful. That is, if this river is degrading, then the breaks in the slopes which are associated with very high stages are probably related to a a former floodplain (Kellerhals and Church, 1980).

There were also problems in selecting a stage associated with some specified discharge interval thought to be related to channel geometry. The stage was not measured at different discharges for each cross-section or even for selected cross-sections. All cross-sections measured by me were surveyed at discharges slightly below mean discharge. Therefore, stage-discharge curves for the various cross-sections could not be developed. The stage-discharge curves for the two gauges are not applicable to the cross-sections in most reaches because of the greatly differing cross-sectional forms, channel slopes, channel patterns, bed materials and vegetational roughness.

The Manning Equation cannot be used to estimate a value because the surveyed slope data are for very low discharges and so are not equivalent to bankfull slopes. The other slope data are from map sheets and so are not accurate enough for such calculations. Also, there is no means for estimating Manning's n, the roughness coefficient, at bankfull and it seems unlikely that it would remain constant with increasing discharge especially in some reaches where bank vegetation is important.

Two measures of bankfull were taken, both employing Wolman's (1955) method because the width and depth data necessary for the calculations were available. In addition to these "break-in-slope" values, the cross-sectional values based on the water level at the time of survey were also used in the data analysis. These "observed" water levels represent approximately the same discharge throughout any given reach, and in fact all the reaches measured by me were surveyed at about the same discharge (Table 3.1).

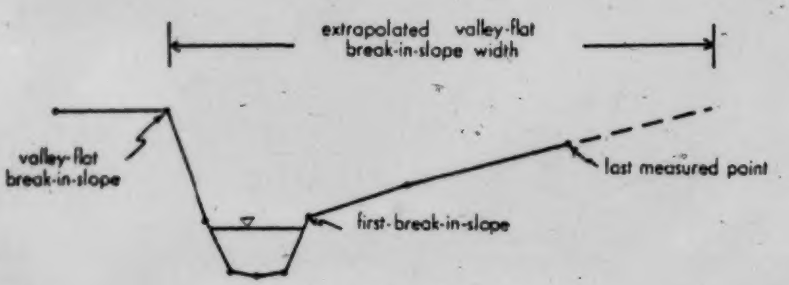
TABLE 3.1. Water discharges at the times that the below-water cross-sections were measured (Canada Inland Waters Directorate, 1980). Cross-section locations are shown on figures 4.1, 4.21, 4.26, and 4.31.

Reach	Cross-section	Discharge	
		Gauge near Fort Saskatchewan (m^3/s)	Gauge at St Albert (m^3/s)
Reach B	1,2,2i,2ii, 2iii,3,4	2.67	1.89
Reach C	1,2,3,3i,4,5	2.67	1.89
Reach C	6,6i	1.81	1.88
Reach C	4i	1.74	1.76
Upstream of Reach D		1.86	1.72
Reach D	1,2,3,4,5,6	2.47	2.50
Reach E	1,2,3,4,5,6	2.57	2.56
Reach F	1,2,3	3.10	2.85
Reach F	4,5,6	2.72	2.80

As depth gradually increases from the channel bottom upwards, the water level where the width first begins to increase rapidly with a small increase in depth is called the "first-break-in-slope" water level. In portions of reaches A to C, the first-break-in-slope water level is at approximately the observed water level. This is referred to here as the "first-break-in-slope" stage. This "first-break-in-slope" value for these reaches sometimes represents a relatively high frequency discharge in comparison to the bankfull frequencies given in the literature. Therefore, the break in the slope of the (width vs depth) line which occurs where the valley flat begins was also used in the analysis, and is referred to here as the "valley-flat break-in-slope". For the Reaches D, E, and F, the "first-break-in-slope" is close to or equal to the "valley-flat break-in-slope" for most cross-sections.

A major problem arose in measuring the valley-flat break-in-slope data, particularly for Reaches B and C as well as for some cross-sections in other reaches. The cross-sections which I surveyed were not always long enough to attain the valley-flat break-in-slope elevation on both sides of the cross-section. In order to get a rough approximation of this value, the measured data were extrapolated using the last two data points (Figure 3.2). This is meant to provide only a qualitative comparison to the first-break-in-slope data for reaches B and C, and the values were rarely used for mathematical analysis. In the

Figure 3.2 Extrapolation of a valley-flat break-in-slope cross-section.


extrapolated valley-flat break-in-slope width
valley-flat break-in-slope
last measured point
first-break-in-slope

other reaches, the extrapolated lengths are small and the cross-sectional values are thought to be more reliable.

For both the first-break-in-slope and the valley-flat break-in-slope cross-sections channel width and channel mean and maximum depths were calculated in the same ways as those for the observed data (see Section 3.2.2). Channel area was calculated by multiplying width times the mean depth.

For the slope-discharge relations, a number of different values for bankfull discharge are used here. For the reaches where the channel appears to be entrenched, the mean annual flood, 24.1 cumecs (Neill *et al.*,1970) is used for the bankfull value (Ackers, 1980). For the reaches near St Albert, the bankfull values calculated by Szabon (1975) and Simpson (1977) are used. The mean annual flood is used for the other reaches for convenience.

3.3 Sediment Sampling

3.3.1 Gravel sampling

No bulk samples were taken from the gravel beds primarily because of the inconvenience of removing and transporting the gravel to the lab for analysis. Instead, measurements of the intermediate axes of the pebbles were taken in the field along grids on channel cross-sections. Kellerhals and Bray (1971, p.1172) showed that the combination of grid sampling of the surface layer of a paved gravel deposit and frequency by number, rather than by weight, yields a result equivalent to a "sieve curve of an imaginary nonpaved deposit whose surface layer is identical to the surface layer under investigation". Thus, the results of "grid-by-number" analysis are directly comparable to results of bulk sampling using frequency by weight, used for the sand samples. However, there are several problems with this method. There is a higher probability of selecting larger particles because the larger particles cover a larger portion of the bed (Leopold, 1970). Furthermore, only the gravel on the surface of the bed is measured and so there is no information on the underlying sediments.

Only the intermediate axes of pebbles were measured (e.g. Leopold, 1970; Hack, 1957; Church and Kellerhals, 1978) and the means and standard deviations obtained from the resultant distributions (Section 3.5). Because only these statistics were used in the subsequent analysis, it was felt that the extra time required for measuring the other two axes was not justified.

A variety of sample sizes have been used in the literature. For example, Church and Kellerhals used a sample size of 50 stones while Hack (1957) and Leopold (1970) used 100 stones. For this study, a sample size of 60 was used. Measurements were made to the nearest millimeter, using a ruler. To sample at a given cross-section, a variation on Hack's (1957) method was used. A calibrated rope was stretched across the channel, with a smaller, four-foot long rope attached and allowed to float parallel to the direction of flow of the river (Figure 3.3). At one foot intervals along the main rope, five samples were taken, each one foot apart, along the smaller rope.

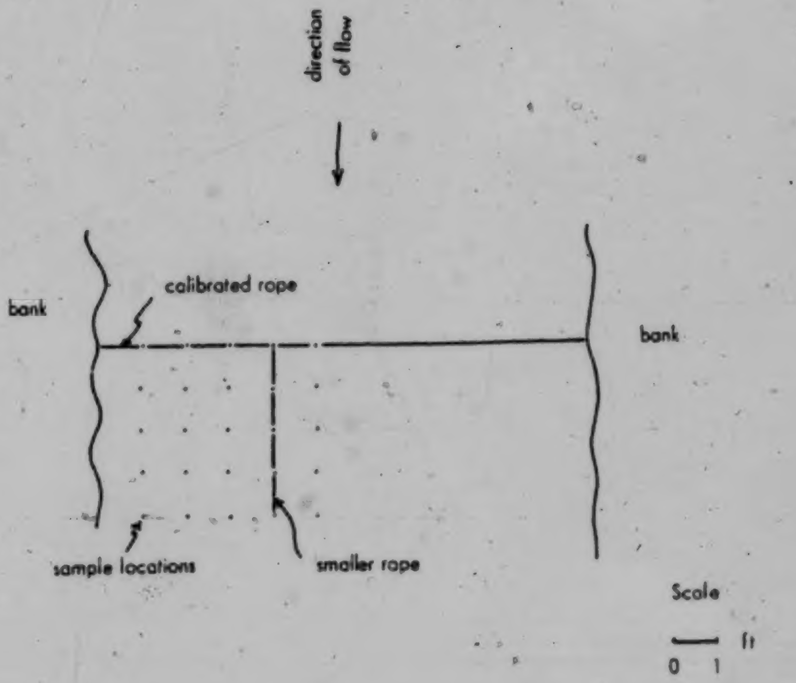
In all cases, either the water had a high suspended load, or the gravels had algae growing on them. This reduces the problem of observer bias in, say, selecting relatively larger rocks, because the gravel on the bed could not be clearly seen. If a piece of gravel was large enough to be sampled twice, i.e. greater than one foot in diameter, it was not sampled twice, but a different rock was sampled at the next sample site although, according to Kellerhals and Bray, (1971), this is not the correct procedure.

The gravel data are generally poor because too few samples were taken, and of those taken, not all were measured at comparable places along the channel (for example all at riffles or all at bends).

3.3.2 Sampling of Fine Sediments

An Eckman grab sampler was used to obtain bottom samples of fine sediment. The bed sediments were sampled from the deepest part of the channel except in a few instances where the bottom was too deep to be reached from the boat with the sampler (i.e. a depth greater than about 2 m). In these cases, the deepest spot which could be reached was sampled. Bank samples were taken from both banks, at or near water level. Samples of the fine sediments were taken

Figure 3.3 Gravel bed sampling method.



at cross-sections where cross-sectional data had been measured, as well as between measured cross-sections. Samples were taken at successive bends and cross-overs along each reach (details of the locations are given in the discussions of individual reaches). Where vegetation covered the surface at sample points, it was removed. The bed samples sometimes included bottom fauna, mostly bivalves, which were retained and removed in the lab.

At some cross-sections, more than one bed sample or more than one bank sample was taken. Because this was usually done only where there appeared to be distinctly different types of sediment present, there are very few data concerning the variation in sediments across a given cross-section. These data would have been very useful, especially when trying to evaluate the importance of small downstream variations in sediment size. Analysis of the few duplicate samples which were taken is discussed in Section 3.4.3.

3.4 Laboratory Analysis of Sediment Size

The sediment samples were analysed in the laboratory for grain size. The sand-sized particles were dry sieved and hydrometer analysis was used for the silt-sized particles.

3.4.1 Hydrometer Analysis

Sediment sizes for the silt portion of the sediment samples were obtained by hydrometer analysis. Pipette analysis is considered to be more accurate, precise and reproducible than hydrometer analysis (e.g. Day, 1965; Beverwijk, 1967). However, it was felt that the time saved and the convenience achieved by using the hydrometer outweighed the benefits of the pipette. Ultimately, the sediment data were to be generalised into variables such as mean sediment size, percent silt-clay, and Schumm's M (see Section 3.5.2). Because of this, the more refined data obtained by pipette analysis were not necessary. For detailed discussions of hydrometer analysis and settling theory see Day (1950,1965), Müller (1967), Galehouse (1971), and Brady (1974).

The particular hydrometer method used here was the American Society for Testing and Materials (1978) Procedure for Particle Size Analysis of Soils, ASTM designation "D422-63(1972)". This procedure was used because it was easy to follow, and was referred to or utilised by other investigators (e.g. Galehouse, 1971; Ingram, 1971; and Locker, 1973). Some modifications of the ASTM procedure were found to be necessary. The ASTM procedure with these modifications is given in Appendix I.

To disperse adequately samples with a high clay content, it was necessary to increase the mixing time from one minute to five minutes. Bouyoucos (1936) recommended a five minute stirring time for sands, ten minutes for most other soils, and for soils difficult to disperse, twenty to thirty minutes. However, Day (1965) stated that most changes induced by mechanical mixing occur in less than five minutes and that soft rock fragments will disintegrate under prolonged mixing and so increase the amount of fines.

If the sample failed to disperse after five minutes of mixing, the concentration of the dispersant was increased from four percent to ten percent (Galehouse, 1971). If, despite increased mixing and higher dispersant concentrations, the sample still failed to disperse, the sample weight was reduced from about 50 to 60 grams to about 40 grams (Galehouse, 1971).

Two of the field samples were taken from highly organic soils. These would not disperse because the organic matter interferes with the dispersion (Ingram, 1971), and so they were not analysed for sediment size, although the amount of organic matter was determined by combustion (heating to 540° C). It is possible to remove organic matter by using a hydrogen peroxide treatment (Ingram, 1971). The large amounts of organic matter would have necessitated long treatments with hydrogen peroxide. Akroyd (1957, p.63) stated that "appreciable errors may be introduced by the action of large quantities of peroxide". Also, none of the other samples were treated with hydrogen peroxide and it was felt that the results from these two samples would not necessarily be comparable with all the other sample results.

In certain reaches, the channel bottom was covered with large numbers of gastropods and bivalves. Because these were not removed in the field, the sediment samples inevitably included large numbers of shells and shell fragments. These shells were picked out manually which meant that small fragments remained in the analysed samples. The alternative to manual removal would be to dissolve them in HCl (Ingram, 1971). It was believed that the time necessary and the large amount of HCl required to dissolve the shells made manual removal acceptable (Akroyd, 1957; Ingram, 1971). However, the shells and shell fragments affect the hydrometer analysis because of their erratic settling paths (Braithwaite, 1973), thereby interfering with the settling of the other particles by direct contact and indirectly by causing turbulence in their wake.

A hydrometer bath was used to maintain a constant temperature in the sedimentation cylinders. The temperature of the bath was measured frequently, and it was found that only very small changes in temperature occurred over the 24 hour period required for the silt-sized particles to settle.

3.4.2 Sieving

The coarse portions of the samples were analysed using the ASTM D422-63(1972) procedure for dry sieving with some modifications, as given in Appendix I.

Mechanical sieving was used and the samples were shaken for ten minutes, a time within the limits suggested by some investigators (e.g. Müller, 1967; Cadle, 1955; and Ingram, 1971). The sieve nests had half phi intervals for well-sorted sands and whole phi intervals for poorly sorted sands usually from the tails of silty or clayey samples. Half phi or quarter phi units are often recommended, especially for identifying the subtleties in the tails of the distributions (Folk, 1966).

Some decisions were made with respect to sieving after hydrometer analysis. When 5 to 15 grams of sand remained after hydrometer analysis, another sample was prepared to obtain more sand for sieving. If there were less than 5 grams of sand remaining, the weight of the entire sand fraction was recorded and the sample was not sieved.

3.4.3 Reproducibility of Laboratory Analyses

In some cases, a pair of samples were analysed from a single field sample in order to check the replicability of the laboratory sediment size analyses. The chi-squared goodness of fit test was used to compare the entire frequency distributions of the duplicate laboratory samples (Eisenhart, 1935; Speigel, 1961). To calculate chi-squared:

$$\text{chi-squared} = \sum_{i=1}^{n} (O_i - E_i) / E_i$$

where:

n = sample size;

O_i = ith observed value,

and E_i = ith expected value.

The chi-squared test rejects the null hypothesis, and accepts that the observed distribution is different from the expected distribution when the difference between the two distributions is large. When this difference is small, the null hypothesis is accepted and the fit of the distribution is said to be "good". When the difference between the two distributions is extremely small, the fit is said to be "too good", that is, "the probability of choosing samples that agree so well from all possible samples is so small that one suspects that they were not random" (Eisenhart, 1935, p.142).

For this test, it was necessary to let one of the pair of samples be the expected distribution. The resulting chi-squared value depends on which sample distribution is chosen to be the expected distribution. Therefore the calculations were done twice for each pair of samples, alternating the sample distribution used for the expected distribution. If the null hypothesis was rejected in either case, the samples were taken as being statistically different from each other. Because the frequencies in the tails of the distributions were usually small, it was necessary to group the data to avoid very large chi-squared values which could result from division by very small expected values (Breiman, 1973, pp.199-200).

Several types of sediments were tested in this way: fine to medium sands, sandy silts, silts and silt clays. The fits for all these were either "good" or "too good" at the

0.05 level of significance. A fit which is "too good" is not surprising given that the comparison is between two samples both derived from the same original grab sample. These results indicate that the laboratory tests were reproducible.

Unfortunately, very few duplicate field samples were taken. The chi-squared goodness of fit test was applied to duplicate bed samples in the silty-clay sediments. There are duplicate samples from three cross-sections and all were significantly different. A pair of samples was also taken at a cross-section composed primarily of silty sand. The fit was "good" between these two distributions.

Duplicate field samples of bank sediments were taken only when the bank sediment changed markedly at a location, so there are no quantitative data on the variations in bank sediments at most cross-sections.

3.5 Computation of Sediment Size Measures

3.5.1 Graphical and Moment Measures

In Appendix III are listed the cumulative frequency data for the sediment samples. All the sediment data were plotted on graphs of percent cumulative frequency against sediment size. This was done in order to look for "kicks" in the curves where one or two points do not correspond to the general curve. These are usually caused by errors in the laboratory sediment size analyses. Several measures of the sediment size characteristics were calculated using the numerical data.

The measures of sediment size characteristics most commonly used in the literature (e.g. Folk and Ward, 1957; Flemming and Poodle, 1970; Friedman and Sanders, 1978) are: measures of central tendency such as the mean or median; measures of dispersion such as the standard deviation or a sorting coefficient; measures of skewness; and measures of peakedness or kurtosis. These can be determined graphically or computationally.

The graphical approach was developed when the computation of statistical moments was performed without computers (Friedman and Sanders, 1978). Graphical measures use only a few points of the distribution whereas moment measures take into account the whole distribution (Folk, 1966). It was decided to use moment measures to calculate the means and the standard deviations of the samples. The equations for these calculations are given in Friedman and Sanders (1978, p.78-80). According to Folk (1966, p.80), the mean computed by the method of moments is the "best measure of overall size". The mean was used frequently in the correlation and regression analyses.

To calculate moment measures, the entire distribution must be known. This necessitated extrapolation of the measured data because the clay fraction was not analysed. Hydrometer analysis is based on Stoke's Law of Settling and so this form of analysis cannot determine sediment diameters for particles smaller than about 9 phi, where Stoke's Law does not apply (Galehouse, 1971). Hence, there are no data for the clay-sized portions of the sediment samples. The clay-sized portions form quite large percents of some samples and even graphical measures would require extrapolations.

Extrapolation requires some arbitrary assumptions about the unanalysed fraction. Folk and Ward (1957) graphically extrapolated the last known point from pipette or hydrometer analysis to 14 phi, using a straight line on arithmetic paper. There is no reason to suppose that the distribution necessarily would form a straight line on arithmetic paper, although Folk and Ward (p.13) believe that it is "probably not too wide of the mark". When percent cumulative frequencies are plotted against sediment diameters, in phi units on probability paper, the distributions often approach normality i.e. the data plot as straight lines (Inman, 1952). In many cases, sediment distributions are composed of several straight lines of differing slopes, separated by sharp breaks in the curve (Friedman and Sanders, 1978). The distributions usually divide into three regions which are thought by some to represent suspended load, intermittent suspended load, and traction load (Viard and Breyer, 1979).

It was assumed here that the clay sediments were carried as suspended load. The line for silt sizes was extrapolated into the clay range so that the data for clay sizes formed a straight line on probability paper. The program for this was written by John Honsaker of the University of Alberta. There seems to be stronger basis for this extrapolation than for the method of Folk and Ward. However, it is not entirely correct to assume that the clay-sized sediments are always carried as suspended load. Because of the cohesiveness of clay, the particles may not be carried as discrete particles but rather as aggregates and transported as suspended, saltation, or traction load. Hydrometer analysis involves dispersion of the clays so that they do not occur as aggregates. Therefore, there are no data for clay aggregates in this study.

The data were extrapolated arbitrarily to 20 phi. Although 20 phi is a very small size, it was selected in order to avoid a large percent of the distribution being unaccounted for.

3.5.2 Other Measures of Sediment Size Characteristics

Schumm, in several papers (1960a,1960b,1961a,1961b,1963,1967) postulated the channel cross-sectional form and planform are significantly related to the amount of silt and clay in the channel perimeter. Schumm calculated a weighted mean percent silt-clay, M, such that:

$$M = (\%SCBD \times W + \%SCBK \times D)/(W + 2D)$$

where:

%SCBD = percent silt-clay in the channel bed,

%SCBK = percent silt-clay in the channel banks,

W = channel width (possibly for a 2.33 year recurrence interval discharge),

D = channel depth (possibly for a 2.33 year recurrence interval discharge).

There has been some criticism of this variable (Section 2.10) and other variables such as %SCBK, %SCBD and the median grain size have been proposed as statistically better than M.

M, %SCBK, and %SCBD were all calculated for the Sturgeon River sediment data. Also, the percent of clay in the banks, %CBK, and in the bed, %CBD, were determined. The percent clay was calculated to better judge the effect of the cohesive portion (Section 2.10).

3.6 Channel Planform Measures

3.6.1 Sinuosity

Sinuosity is a measure of the degree of channel meandering. There are several methods for measuring channel sinuosities (see for discussions, Brice, 1964; Mueller, 1968). Sinuosity was calculated by the method most commonly used (Lane, 1957; Schumm, 1963), that is, the channel length divided by the valley length, Sin. This sinuosity value is used here for the mathematical analysis of the relations between sinuosity and other variables because of its comparability with values in the literature. The location of the thalweg is not known for the study reaches and so the channel length was measured along the channel centreline. Sinuosity was measured on 1:12000 map sheets made from air photographs taken at various times in 1967 (Alberta Department of Agriculture, 1967). These photographs were taken at relatively low discharges and so the compound meander pattern (Section 2.4)is visible. The valley length is the length of the valley axis, the line which bisects the valley bottom longitudinally.

3.6.2 Radius of Curvature, Wavelength, and Amplitude

These three variables were measured generally following Brice's (1973) method. The radius of curvature was determined by selecting the circle whose curvature best-fitted the curvature of the centreline of the bend. Measurements were made on the 1:12000 map sheets described above. In some cases, the fit of the curve was very good. On other bends the curve selected intersected at least with the centreline bend apex and the two inflection points (see Figure 3.4). The inflection points were chosen to be halfway between bend apices for these cases. The radii of these circles are the values of the radii of curvature, Rc, used for analysis.

Chords were drawn between the intersections of successive arcs (Figure 3.4). Where a bend was adjacent to a straight reach, the chord was drawn from the point where the

Figure 3.4a Measuring radius of curvature, Rc, meander wavelength, L, and meander amplitude, Amp.

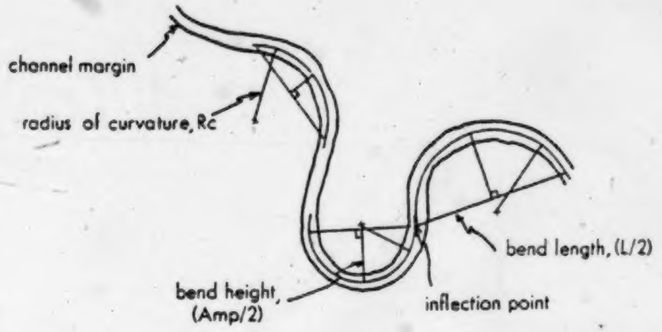
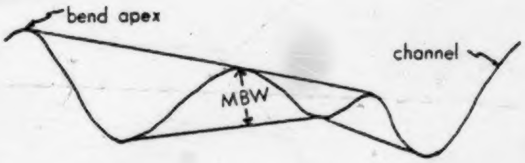


Figure 3.4b Measuring meander belt width, MBW.



bend and the superimposed arc ceased to coincide. Meander wavelength, L, is twice the chord length.

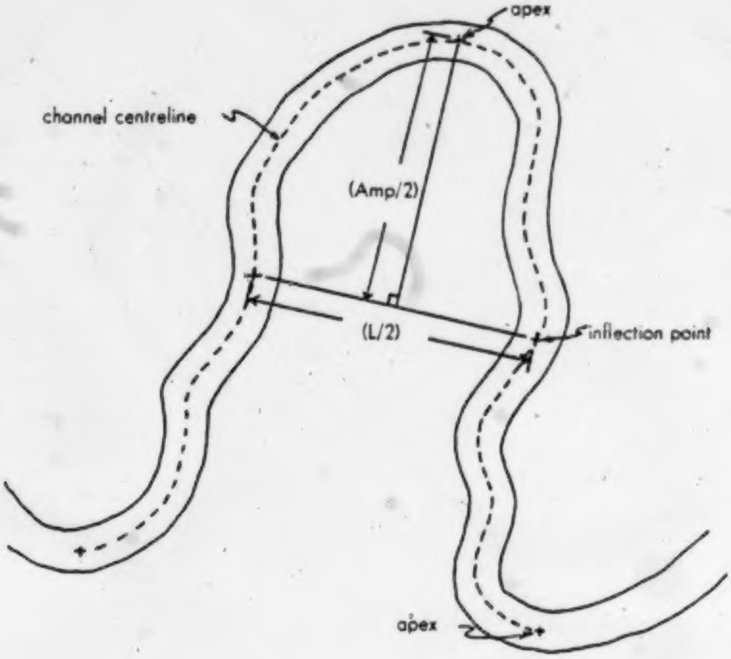
Bend height was measured perpendicularly to the chord, from the chord to the apex of the arc (Figure 3.4). Meander amplitude, Amp, was calculated as twice the bend height.

One difficulty with this method is that it provides statistics for only simple meander loops, and the small meanders within the compound loops. To measure the planform characteristics of the large bends of the compound loops, inflection points were designated to be halfway between the bend apices of successive large bends. Frequently, the selection of the apex location was somewhat arbitrary. The inflection points were joined by lines and perpendiculars drawn to the maximum height of the stream centreline (Figure 3.5). Meander amplitudes and wavelengths were calculated from the lengths of these lines. There does not seem to be a method of fitting a circle to the large bends in order to determine the radius of curvature. A large number of circles fit depending on exactly where the inflection points are placed. Therefore, only meander wavelengths and amplitudes were measured for the large meander planforms.

3.7 Channel and Valley Slopes

Yaremko (1968) provided channel slope data (Figure 4.6) for the Sturgeon River just downstream from Big Lake. The channel slope through St Albert in December, 1975 (Figure

Figure 3.5 Measuring meander amplitude, Amp, and wavelength, L, for large bends within compound meanders.



4.6) is from Szabon (1975) and the Alberta Environment Planning Division surveyed the slope from Big Lake to the bridge west of Namao (Figure 4.6). All three slopes were measured at relatively low discharges.

Channel slope is very low for the Sturgeon River from Big Lake through to the bridge west of Namao. Thus, small errors in measurement can make significant differences in the slope values. For both the Szabon and Planning Division slope data, there are small portions where the measured water surface actually rises with increasing distance downstream. The Szabon slope measurements were taken when ice was on the river. Perhaps ice flows piled up behind bridge constrictions causing higher measured elevations. Therefore, the slope data were averaged over each portion of the reaches involved, to remove the effects of these small rises.

The other slope data used for this study were measured from the 1:12000 topographic maps and are of poor quality. The contour interval on these sheets is approximately 3 m, and so does not provide a very detailed picture of slope along either the valley or the channel. The valley bottom slope was calculated using the drop in the water surface elevation divided by the straight line distance (Ackers and Charlton, 1970b).

3.8 Valley Widths and Meander Belt Width

The valley bottom and top widths were measured perpendicularly to the valley bottom centreline on the 1:12000 topographic maps. The valley bottom is the valley flat for reaches D, E, and F. Along reaches A to C, the valley bottom is Surface I, shown on Figure 4.1. The meander belt width is measured as shown on Figure 3.4.

3.9 Data Analysis

The relations between the channel perimeter sediment characteristics, the channel cross-sectional characteristics, the channel and valley slopes, and the channel planform characteristics were analysed using simple and multiple least squares log-linear regression and simple and multiple correlation.

3.9.1 Correlation

The correlation coefficient, r, is a measure of the degree to which variables are linearly related. Both X and Y must be random. The values of r range from +1, perfect positive correlation, to -1, perfect negative correlation. When r is equal to zero, there is no linear relation between the two variables. The significance of the value of r depends on the sample size, especially for small samples (Wonnacott and Wonnacott, 1972). The coefficient of determination, r^2, is a ratio of the explained variation of

Y to the total variation of Y.

R and R^2 for multiple correlation correspond for r and r^2 for simple correlation. As variables are added to the correlation, the size of the increase in the R^2 value indicates how much the additional variables are improving the explanation of Y (Wonnacott and Wonnacott, 1972).

3.9.2 Regression Analysis

Simple and multiple regression analyses have been used commonly in the literature when considering relations between sedimentary, cross-sectional and planform variables (e.g. Leopold and Wolman, 1960; Schumm, 1967; Miller and Onesti, 1979). This is the form of analysis which is used here in order to describe the relations between variables and to compare relations for the Sturgeon River data sets with relations given in the literature.

Least squares linear regression should be used only to form a predictive equation. According to Mark and Peucker (1978), it is inappropriate to use this analysis for describing a relationship or to test a model or hypothesis. For these purposes, "functional" or "structural" analysis should be used. Only when the independent variable is free of error, or the coefficient of determination, r^2, is very close to perfect correlation will the line obtained by linear regression be the same as that obtained by functional analysis.

If both the dependent and independent variables have errors associated with them, then the line resulting from linear regression of the variable X on the variable Y will be different from that resulting from the regression of Y on X (Wonnacott and Wonnacott, 1972). Therefore, one must be able to decide which is the dependent and which is the independent variable. In a fluvial system, where all the variables interact, it is difficult to determine physical dependence. Furthermore, "statistical dependence has nothing to do with physical [dependence]" (Mark and Peucker, 1978, p.53). Thus, there is no obvious method of choosing which variable is to be the dependent variable.

Structural analysis distributes the residual variance, due to measurement errors and random effects, among the variables (Mark and Church, 1977). The calculation of the slope of the equation includes λ, a ratio of the unexplained variance of Y to that of X. If this ratio is greater than 100, Y can be regressed on X and if it is less than 0.01, X can be regressed on Y and the relations obtained will be similar to that obtained from structural analysis. However, "...in all other cases the regression analysis underestimates the slope" (Mark and Peucker, 1978, p.55).

Unfortunately, there are no quantitative data on relative error terms for the data here, so structural analysis is not possible. Some of the slopes were recalculated for meander wavelength as a function of the radius of curvature setting λ equal to 1. The slopes from the structural relations were similar to those obtained by linear regression and only sometimes was the linear regression slope an underestimate of the structural slope.

A primary concern in the present study is how the other variables affect the planform characteristics. Therefore, the planform variables were chosen as the dependent variables, even though, as noted, there is no statistical basis for this decision.

In order to compare the relations here with those found in the literature, it was assumed that the equations were of the form: $Y = a X^b$

and, for regression analysis, the transformation:

$$\ln Y = \ln a + b \ln X$$

was made. Thus, the scatter of points were fitted with a log-linear equation. This transformation of the data assumes that the errors in the first equation are multiplicative, i.e. as the values of Y increase, the errors also become large (Wonnacott and Wonnacott, 1970). This may not always be a valid assumption.

One of the assumptions for least-squares multiple regression is that the independent variables are not correlated. According to Jones (1972, p.203):

> "The least squares estimates of the regression coefficients differ unpredictably from the true coefficients if the independent variables are correlated. The estimates can be too large in absolute value, and may have the wrong sign."

For the data considered herein, the independent variables are often significantly correlated, and the multiple regression equations are not meaningful in these cases.

Yet another problem is that the relations are often neither linear nor log-linear and putting a straight line through the distributions can obscure some non-linear variations in the data.

Occasionally, a dummy variable was used where there exists a "yes-no" condition. For example, for the Reach D data a dummy variable was added for the "artificially modified - unmodified" condition. That is, the data were from either the portion that was artificially straightened or from the portion that was not artificially straightened. The use of a dummy variable produces two lines, one for each state of the dummy variable. This assumes that each of the two lines has the same slope, and only the intercepts are changed. This may not actually be the case. The other alternative would be to split the data into two sets, one for each condition of the dummy variable, and regress each separately. However, according to Wonnacott and Wonnacott (1972, p.311), if splitting the data into two groups results in small sample sizes, "the very small sample may yield a very unreliable estimate of the slope, and it may make better sense to pool all the data to estimate one slope coefficient."

To determine the significance of the regression coefficient, Student's t was used. The t test assumes that the distribution of the dependent variable is normal but, according to Wonnacott and Wonnacott (1972, p.415) even if this is not the case, the t test remains "nearly valid". Naturally, it must be kept in mind that statistical significance is not necessarily equivalent to geomorphic significance. The equations are referred to here as "statistically significant" if the statistic for the exponent is significant at 90% or more for a two-tailed t distribution. That is, one can say that the exponent is not equal to zero with 90% or more confidence. As noted above, when the sample sizes are very small, estimates of the exponents become unreliable and the statistical significances are often small.

4. DESCRIPTIONS OF THE STURGEON RIVER REACHES

4.1 Introduction

The six reaches of the Sturgeon River are discussed in this chapter in downstream order, beginning with Reach A where the river issues from Big Lake. Most of the reaches were selected to illustrate a downstream transition from one pattern to another pattern. Therefore, for discussion of the upstream pattern, the transitional pattern, and the downstream pattern, the reaches are divided into three portions: upstream, central and downstream. Reaches D and F were selected to illustrate the effects of diversions and in each case, the central portion of the reach is the diverted portion. The approximate boundaries of the different portions are given on maps of the reaches. The base maps for all reach maps are from the 1:12000 map sheets (Alberta Department of Agriculture, 1967). Most of the details on these maps are based on air photograph and map data. No field work was done on mapping and identifying terraces. Valley surfaces, which may or may not be terraces, are delineated on maps and are labelled where necessary to accompany the discussion.

The channel pattern of Reach A changes from straight in the upstream portion to sinuous in the downstream portion. A compound pattern develops at the downstream end of Reach A and continues along the Sturgeon River until the central portion of Reach C. The pattern along Reach B changes from sinuous in the upstream portion to large amplitude meanders in the downstream portion. In Reach C, the large amplitude meanders die out and a contorted pattern emerges in the downstream portion. Reaches A to C are contiguous and are considered as a single unit for some of the discussion. The natural channel of Reach D and the upstream portion of Reach E also exhibit contorted channel patterns. The central portion of Reach D was straightened in 1962-63. The planform of Reach E becomes almost straight in the downstream portion. The channel pattern along Reach F is sinuous in the upstream portion and has compound meanders in the downstream portion. The central portion is almost straight due to natural and artificial cutoffs. The contorted portions of the Sturgeon River are characterised by very wide and deep cross-sections at bends which are very tight. There is a short discussion of these bends in a separate section.

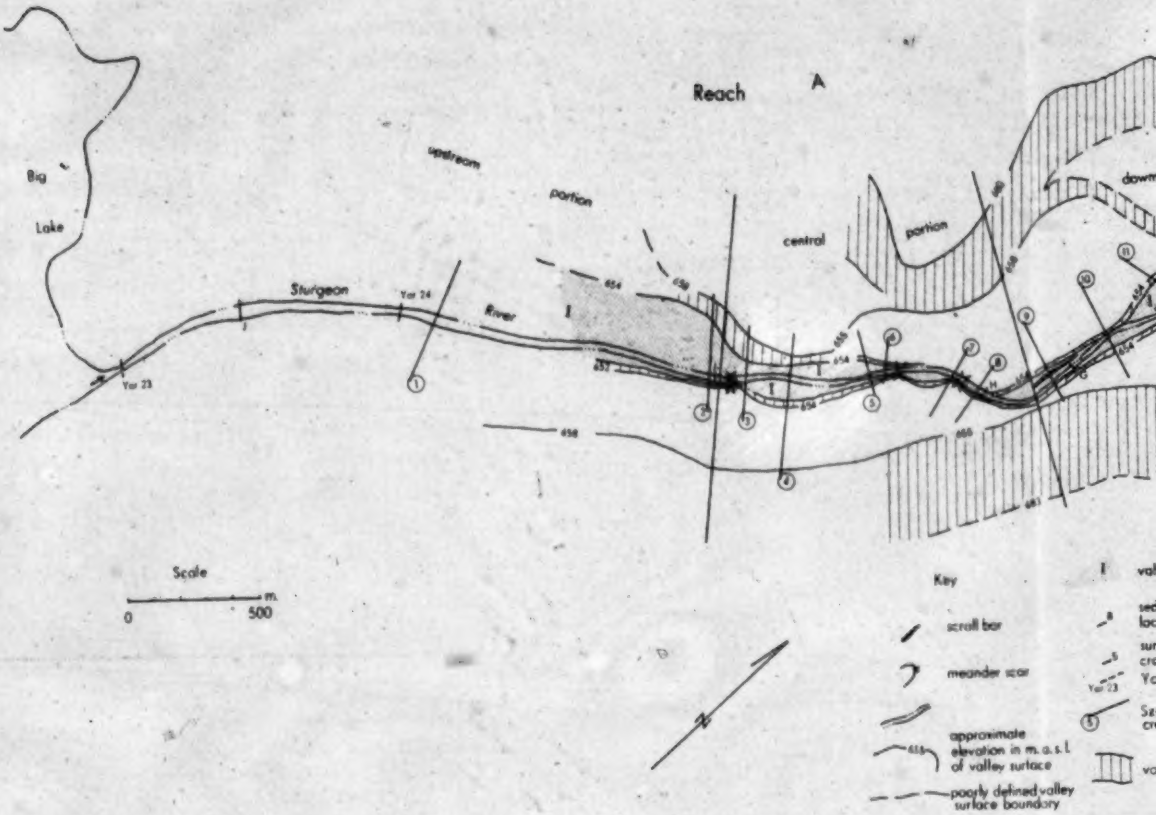
This chapter describes these patterns and discusses, in primarily qualitative terms, the reasons for the downstream variations in pattern with respect to the sediment type, slope, channel form and valley form for each reach. References are made to equations listed in tables by giving the table number followed by the reference number of the equation. For example, (4.2-1) refers to the equation in Table 4.2 with the reference number 1: the data are from Reach A; distance downstream from Big Lake in km, dds, is regressed against the percent of silt and clay in the channel banks, %SCBK; the exponent of %SCBK is -1.24; the Student's t statistic of the exponent is -0.31; the two-tailed significance of this t statistic is less than 50%; the coefficient of determination, r^2, for the correlation between dds and %SCBK is 0.013; and the sample size is 9.

4.2 Reach A

Sinuosity is low along all of Reach A, although there is a slight increase from 1.01 near Big Lake to 1.08 in the downstream portion, where a compound meander pattern develops (Figure 4.1). Generally, meander amplitude and wavelength increase with distance downstream from the central portion of Reach A, until the location of cross-section 14, where the compound pattern begins (Figures 4.1 and 4.2). The amplitude and wavelength of the large meanders continue to increase downstream of this location. It appears that wavelength and amplitude increase to a certain threshold at which point compound meanders are formed. Lewin (1972) and Keller (1972) both postulated that increasing the meander path length would result in the formation of compound meanders (Section 2.4).

The average wavelength for the simple meanders from cross-sections 2 to 13 is 570 m. This is approximately twice the mean value for the small meanders (380 m) and about half the mean value for the large meanders (1220 m) of the

Figure 4.1 The Sturgeon River along reaches A, B and C.



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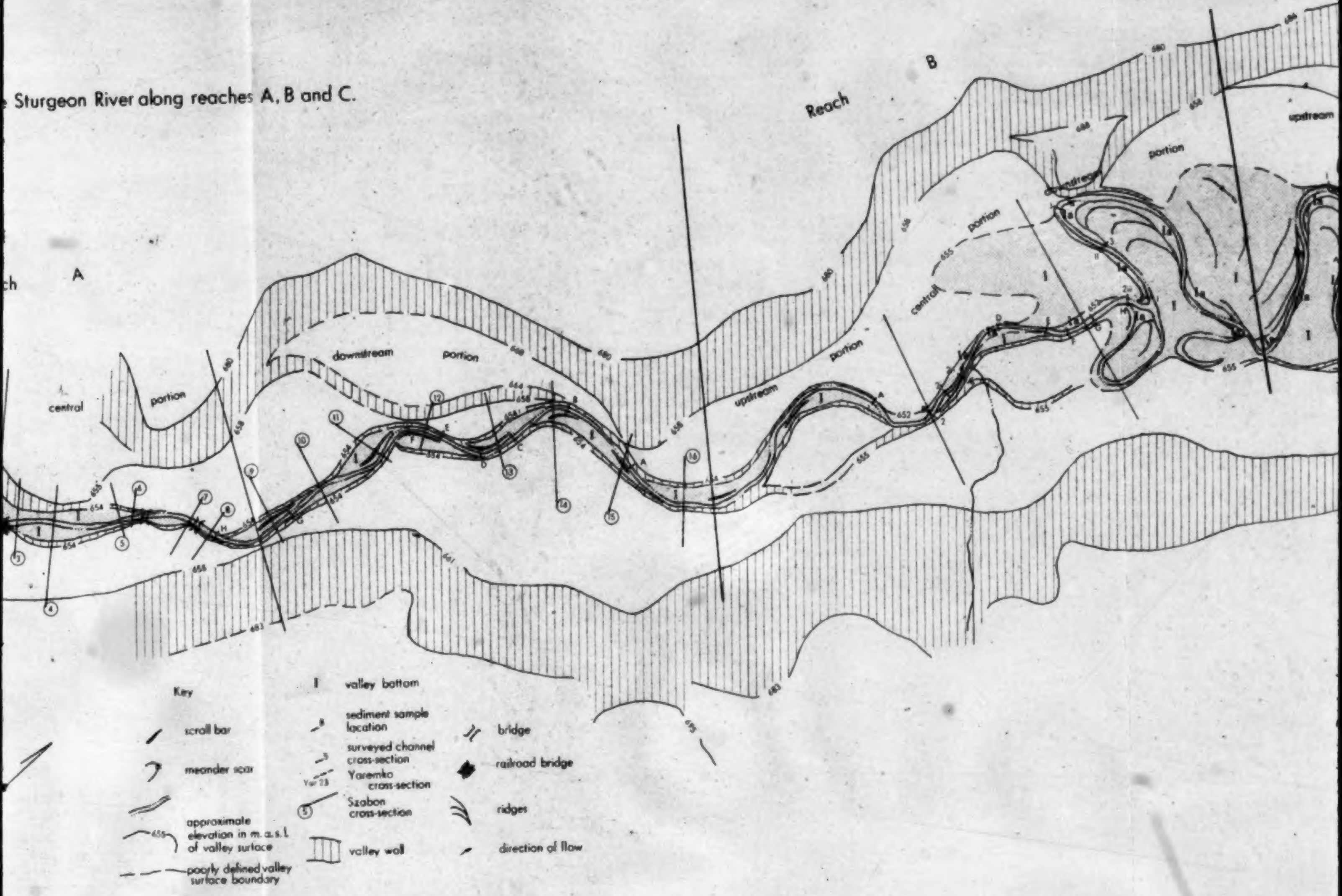
e Sturgeon River along reaches A, B and C.



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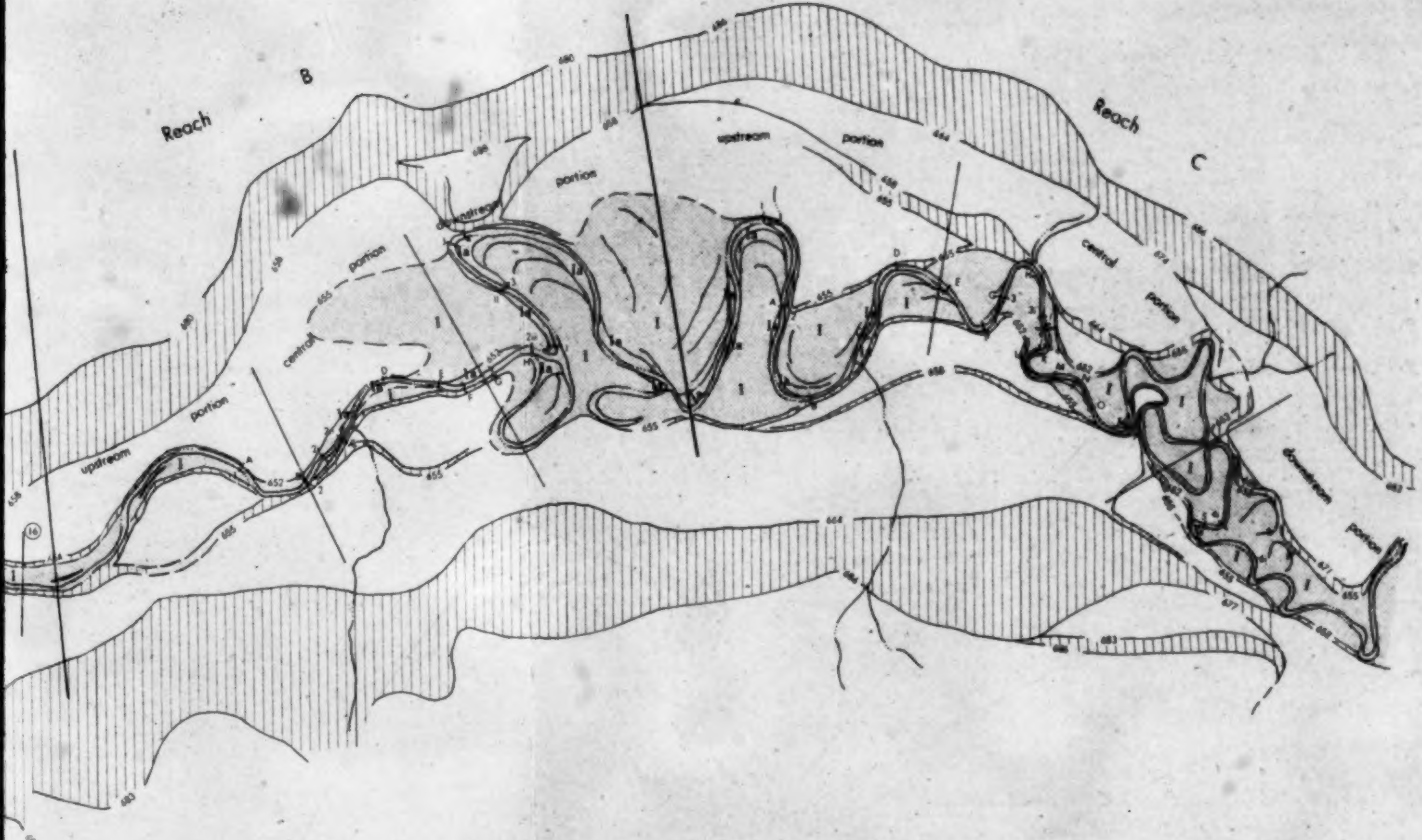
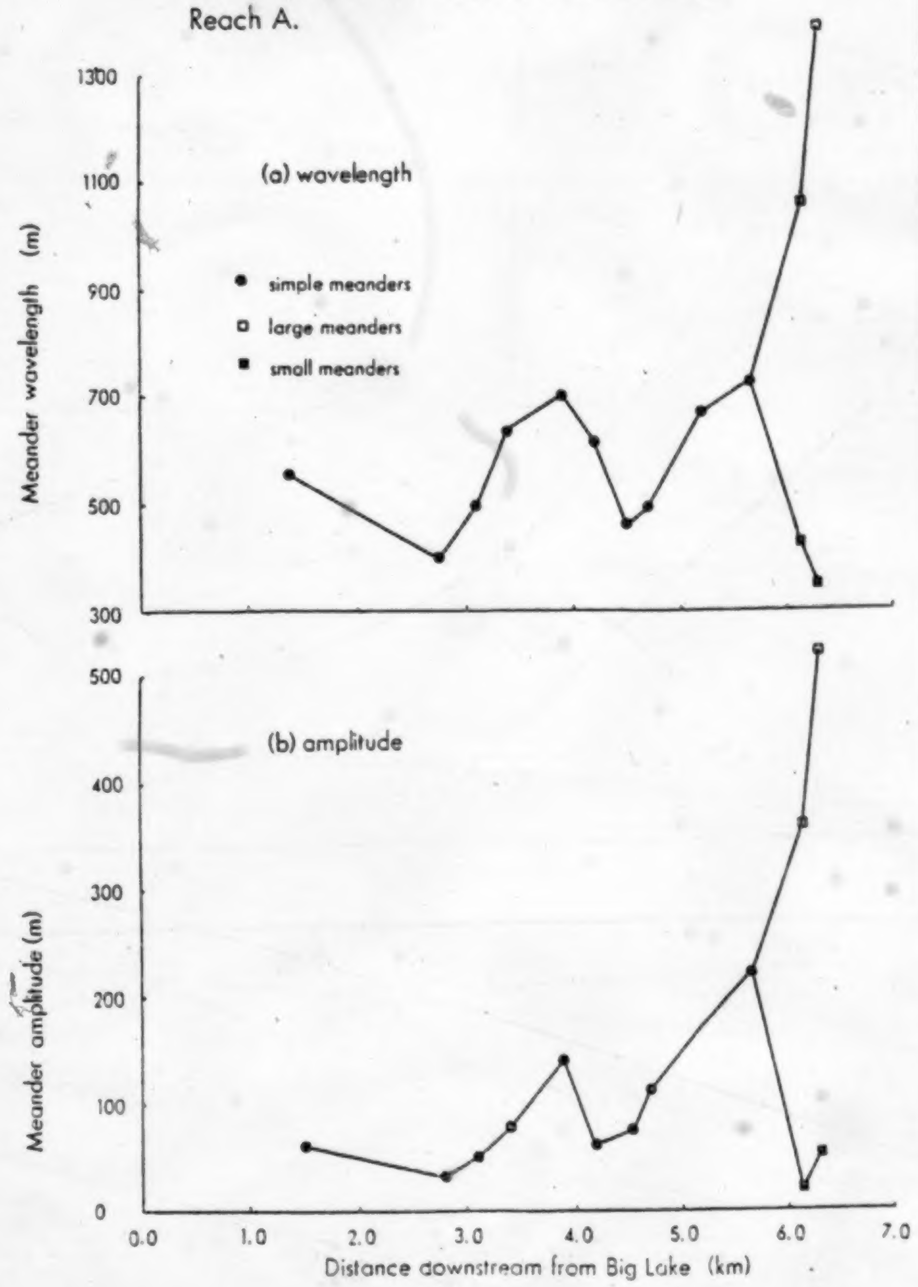

Reach B
upstream portion
central portion
downstream portion
Reach C
upstream portion
central portion
downstream portion
16
652
655
658
664
680
683
686

3 of 3

Figure 4.2 Variations in meander wavelength and amplitude with distance downstream, for Reach A.



compound pattern. Thus, the simple meanders are intermediate in size between the large and small meanders of the compound pattern.

If the valley bottom width is a constraint on meander amplitude, then one would expect that, as the valley bottom width increases, the meanders would grow in size. This growth in meander arc length would then permit the subsequent development of small meanders within the larger pattern. Along Reach A, the valley bottom width decreases from the upstream end to the downstream end (Figure 4.1, Table 4.1) (t=-4.127, 99% significance level) and the valley bottom width shows an insignificant decrease along the downstream portion (t=-0.929, 50% significance level). In fact, the meander amplitudes are larger than the valley bottom widths in this portion because the valley bottom meanders.

The small meanders within the compound pattern are visible only at low discharges and are drowned out when the discharge exceeds about 7 cumecs, from air photo evidence. Hjulström (1949) postulated that the small meanders of a compound pattern may be formed at a low river stage. One would expect from this that the compound pattern would occur along all the Sturgeon River reaches, since the discharge does not change markedly from Big Lake to the North Saskatchewan River. However, this is not the case. For some reason, it occurs in only some portions of the Sturgeon River.

TABLE 4.1. Averaged valley bottom widths and simple or large meander amplitudes for reaches A to C.

Reach	Portion	Averaged Valley Bottom Widths (m)	Averaged Amplitudes for the Simple or Large Meanders (m)
A	Upstream, at cross-section 1	264	61
A	Central	104	53
A	Sinuous	86	111
A,B	Sinuous with compound meanders	69	380
B	Central	64	213
B,C	Large amplitude meanders	710	672
C	Central	253	74
C	Contorted	258	67

Also, one would expect the small meanders to be related to some smaller width, say the observed width or the first-break-in-slope width, and the large meanders to some larger width, say the valley-flat break-in-slope width. Because of the small sample size for the compound portion of Reach A, the statistical relationship between wavelength and width is considered for the data from reaches A to C combined. For the small meanders the relationships between wavelength, L, and the observed width, Wo, and between wavelength and the first-break-in-slope width are not statistically significant (t=1.058 and t=-0.505, respectively). For the large meanders, wavelength is significantly related to the observed (t=2.631), first-break-in-slope (t=2.891), and valley-flat break-in-slope widths (t=1.525) but the weakest of these three relationships is the one for the valley-flat break-in-slope width, Wvf. Thus, there is little statistical support for Hjulström's hypothesis that the two patterns represent adjustments to two different dominant discharges.

The observed width, Wo, and width to depth ratios, (W/Dx)o and (W/Dm)o, decrease with distance downstream (4.2-7 to 4.2-9). The observed cross-sectional characteristics are most variable in the central portion. The cross-sections immediately upstream of bridges are shallower than those immediately downstream of bridges (on Figure 4.3 compare cross-section 2 with 3 or cross-section 7 with 8), suggesting that at least some of the variation in

TABLE 4.2. Distance downstream from Big Lake in km regressed on channel perimeter sediment variables and cross-section variables for Reach A.

Ref. No.	Regressor	Exponent	Student's t of exponent	Two-tailed significance of t (%)	Coefficient of determination, r^2	Sample size
1	Percent of silt & clay in banks, %SCBK	-1.24	-0.31	<50	0.01	9
2	Percent of silt & clay in bed, %SCBD	-0.47	-1.08	50	0.14	9
3	Mean bank sediment size, MBK	1.06	4.55	99	0.75	9
4	Mean bed sediment size, MBD	0.23	1.97	90	0.36	9
5	Percent of clay in banks, %CBK	-2.33	-5.15	99.8	0.75	9
6	Percent clay in bed, %CBD	-0.78	-4.47	99	0.69	9
7	Observed width to max. depth, (W/Dx)o	-0.50	-2.12	90	0.33	11
8	Observed width to mean depth, (W/Dm)o	-0.46	-2.14	90	0.34	11
9	Observed width, Wo	-0.87	-2.45	95	0.40	11
10	Max. depth at observed water level, (Dx)o	0.63	1.13	50	0.12	11
11	Mean depth at observed water level, (Dm)o	0.61	1.35	50	0.17	11
12	Observed area, Ao	-0.40	-0.80	50	0.07	11
13	First-break-in-slope width to max. depth, (W/Dx)fb	-0.41	-1.56	80	0.21	11
14	First-break-in-slope width to mean depth ratio, (W/Dm)fb	-0.39	-1.85	90	0.27	11
15	First-break-in-slope width, Wfb	-0.58	-4.53	99	0.70	11
16	Max. depth at first-break-in-slope water level, (Dx)fb	-0.45	-2.06	90	0.32	11
17	Mean depth at first-break-in-slope water level, (Dm)fb	-0.33	-1.36	50	0.17	11
18	First-break-in-slope area, Afb	-0.32	-3.29	99	0.55	11

TABLE 4.2, continued:

Ref. No.	Regressor	Exponent	Student's t of exponent	Two-tailed significance of t (%)	Coefficient of determination, r^2	Sample size
19	Valley-flat break-in-slope width to max. depth, (W/Dx)vf	-0.17	-0.48	<50	0.03	11
20	Valley-flat break-in-slope width to mean depth, (W/Dm)vf	-0.13	-0.40	<50	0.02	11
21	Valley-flat break-in-slope width, Wvf	0.46	1.76	80	0.26	11
22	Max. depth at valley-flat break-in-slope water level, (Dx)vf	1.08	5.45	99	0.77	11
23	Mean depth at valley-flat break-in-slope water level, (Dm)vf	1.10	4.93	99	0.73	11
24	Valley-flat break-in-slope area, Avf	0.48	3.66	99	0.60	11

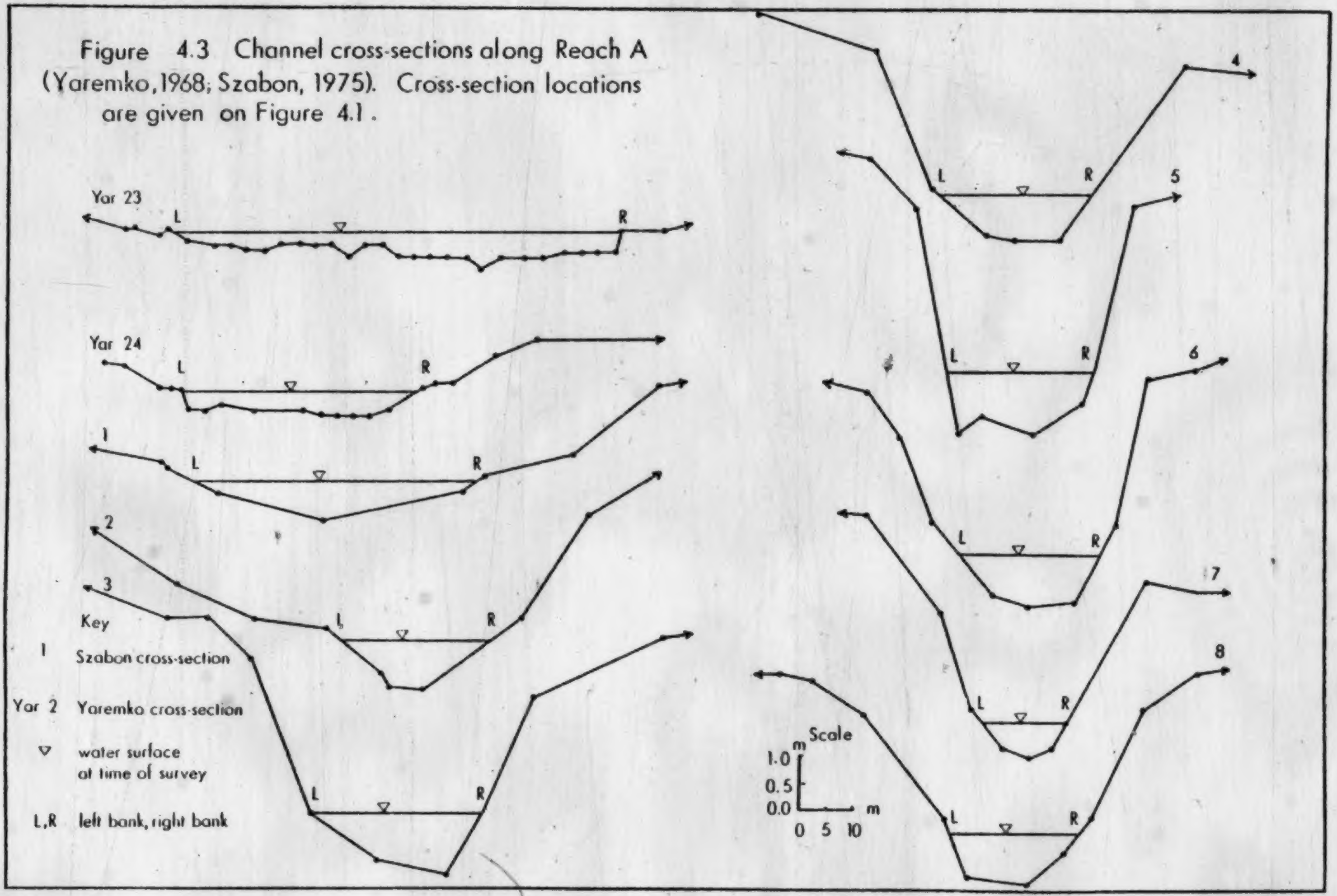


Figure 4.3 Channel cross-sections along Reach A (Yaremko, 1968; Szabon, 1975). Cross-section locations are given on Figure 4.1.

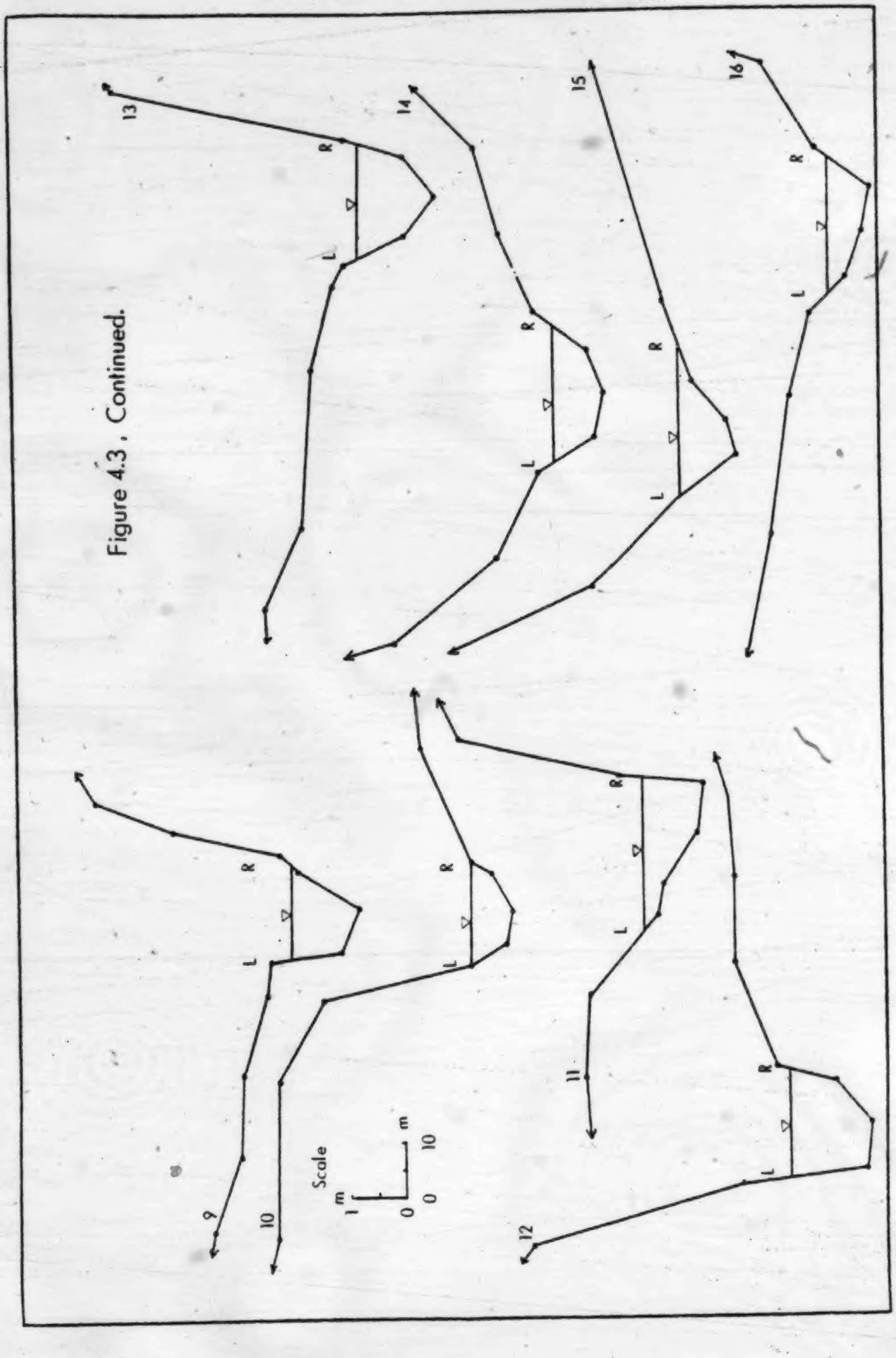


Figure 4.3 , Continued.

this portion is due to artificial modifications.

There are statistically significant downstream decreases in all the first-break-in-slope cross-sectional variables except mean depth, (Dm)fb (4.2-13 to 4.2-17). The stage of the first-break-in-slope data is equivalent to the stage of the valley-flat break-in-slope data in much of the upstream portion (Table 4.3). In the downstream portion, the stage for the first-break-in-slope cross-sections is near to the stage for the observed cross-sections. The portions of reaches B and C which are also characterised by the compound meander pattern also have first-break-in-slope stages approximately equal to the observed values. The transition in the first-break-in-slope size along Reach A occurs between cross-sections 8 and 9, and near to where meander amplitude and wavelength for the simple and large meanders begin to increase with distance downstream. The valley-flat break-in-slope width, Wvf, mean depth, (Dm)vf, maximum depth, (Dx)vf, and area, Avf, significantly increase with distance downstream from cross-section 1 to 16 (4.2-21 to 4.2-24).

No scroll bars were observed in the upstream or central portions of Reach A. In the upstream portion, the channel banks slope gently up from the river (Figure 4.3, cross-sections Yar 23, 24 and cross-section 1); in the central portion, the banks are generally U-shaped (Figure 4.3, cross-sections 3 to 8). The banks in both these portions have been subject to artificial modifications and

TABLE 4.3. Observed widths, Wo, first-break-in-slope widths, Wfb, and valley-flat break-in-slope widths, Wvf, for the Sturgeon River reaches.

Reach	Cross-section	Distance downstream (km)	Wo (m)	Wfb (m)	Wvf (m)
A	Yar 23	0.1	236	--	--
	1	1.56	51.0	115	115
	2	2.68	27.0	90	179
	3	2.79	36.0	50.0	81.0
	4	2.94	27.8	57.5	57.5
	5	3.33	27.3	40.5	40.5
	6	3.40	25.5	50.5	50.5
	7	3.66	15.4	42.0	42.0
	8	3.76	24.0	67.5	67.5
	9	4.07	17.3	20.0	125.5
	10	4.37	19.0	19.0	131.5
	11	4.67	29.5	42.0	161.0
	12	4.98	20.3	21.0	209.0
	13	5.29	21.1	23.0	192.5
	14	5.59	25.1	28.2	125.5
	15	6.06	28.5	20.0	139.5
	16	6.37	25.5	30.5	295.0
B	1	7.44	14.53	13.2	106.0
	2	7.76	13.97	13.6	101.0
	2i	7.92	16.48	--	--
	2ii	8.08	13.69	--	--
	2iii	9.04	13.41	--	--
	3	9.53	15.37	15.8	70.5
	4	9.85	15.65	15.5	145.0
C	1	12.10	12.29	11.0	93.0
	2	12.58	13.69	13.0	184.0
	3	14.35	10.90	10.9	97.0
	3i	14.68	8.94	--	--
	4	14.84	10.34	10.3	76.5
	4i	18.38	10.24	--	--
	5	18.46	11.73	20.5	60.5
	6	18.54	19.56	31.0	31.0
	6i	18.86	10.90	--	--
D	1	53.38	17.32	36.5	36.5
	2	53.46	13.69	34.0	34.0
	3	54.11	17.32	33.0	33.0
	4	54.19	16.21	24.0	24.0
	5	55.15	32.13	36.0	49.5
	6	55.18	15.93	23.5	40.0
E	1i	62.78	17.60	--	--
	2	63.68	15.79	21.0	21.0
	3	64.51	18.44	25.0	25.0
	4	64.75	16.76	23.0	23.0
	5	65.11	20.12	28.5	28.5
	6	65.17	16.76	22.0	22.0
F	1	73.42	16.15	25.5	44.0
	2	73.58	19.00	26.3	34.0
	3	73.82	17.88	22.5	49.5
	4	74.63	18.58	31.2	71.0
	5	75.38	14.53	22.5	45.0
	6	75.46	19.00	25.0	58.0

no conclusions should be drawn as to their natural features. The 1924 air photographs of the reach are not clear enough to enable detection of small floodplain features which may have existed before artificial modifications.

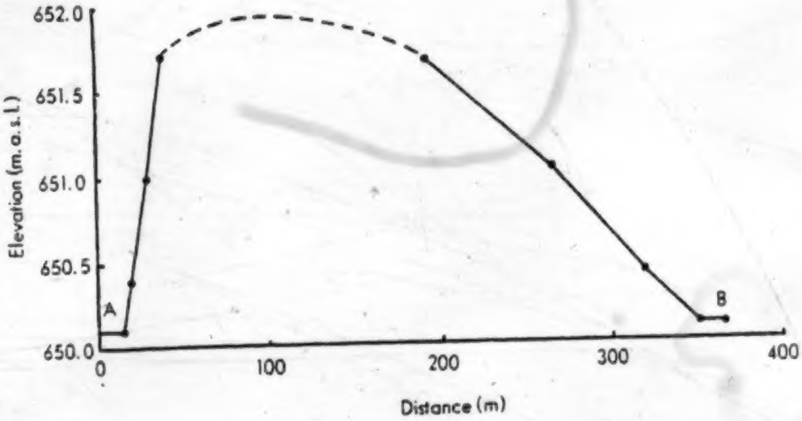
The gently sloping point bars, the cut banks on the outside of bends (Figure 4.3, cross-sections 9 to 16), and the occurrence of scroll bars (Figure 4.1) in the downstream portion are all evidence of meander migration. The pattern of steep upstream and gently sloping downstream banks (Figure 4.4) indicates that the planform is migrating downstream. The lack of meander scars (Table 4.4) on the valley bottom (i.e. Surface I on Figure 4.1) indicates that the entire pattern is moving uniformly downstream, so cutoffs do not form.

The existence of a single scroll bar per point bar (Figure 4.5) suggests that either the depressions associated with older scroll bars have become infilled by overbank deposition or that the phase of river activity responsible for the erosion of Surface I has been active for a geologically short period of time.

The water surface slope for the first approximately 600 m downstream from Big Lake is thought to be very low from qualitative field observations which indicate that the water velocity here is extremely low. A longitudinal bed profile (Figure 4.6a), probably from the mouth of Big Lake to the railroad bridge, shows a rise in the bed over the first approximately 1200 m downstream from Big Lake. The magnitude

Figure 4.4 Cross-section of a point bar in the downstream portion of Reach A

(a) Point bar cross-section.



(b) Approximate location of cross-section

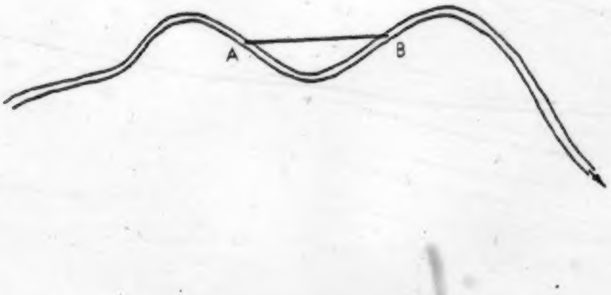


TABLE 4.4. Definitions of some features associated with meandering channels.

Floodplain:	A strip of relatively smooth land bordering a stream and overflowed at the time of high water (Leopold, Wolman and Miller, 1964).
Point bars:	The loci of deposition on the convex side of the river bends (Leopold, Wolman and Miller, 1964).
Scroll bars:	Depressions and rises on the convex side of bends, formed as the channel migrates (Leopold, Wolman and Miller, 1964).
Meander scars:	Meander bends abandoned by cutoffs (which may or may not be occupied by water) (Thornbury, 1969). These are called oxbow lakes when occupied by water.
Chutes:	Depressions on point bars which act as overflow channels (Thornbury, 1969).
Benches:	Accreting flat-topped bodies of sediment occurring along the banks of a stream channel (Woodyer, Taylor and Crook, 1979).

Figure 4.5 A scroll bar located on point bar at cross-section 14 in the downstream portion of Reach A.

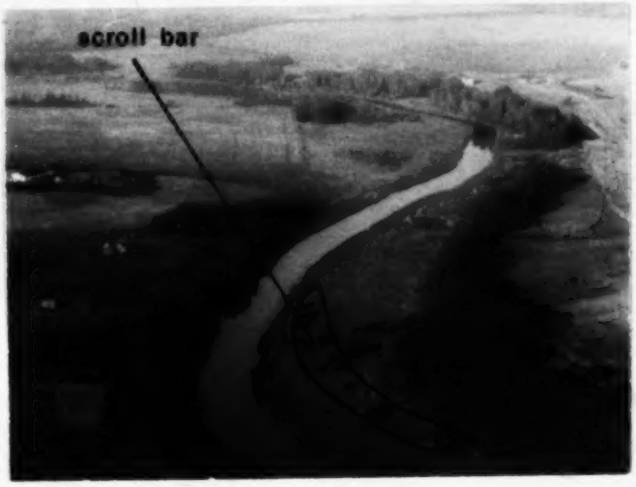
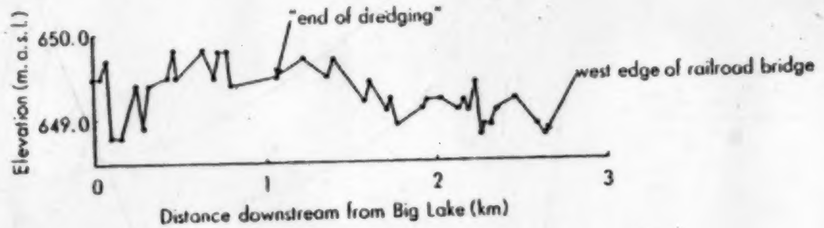
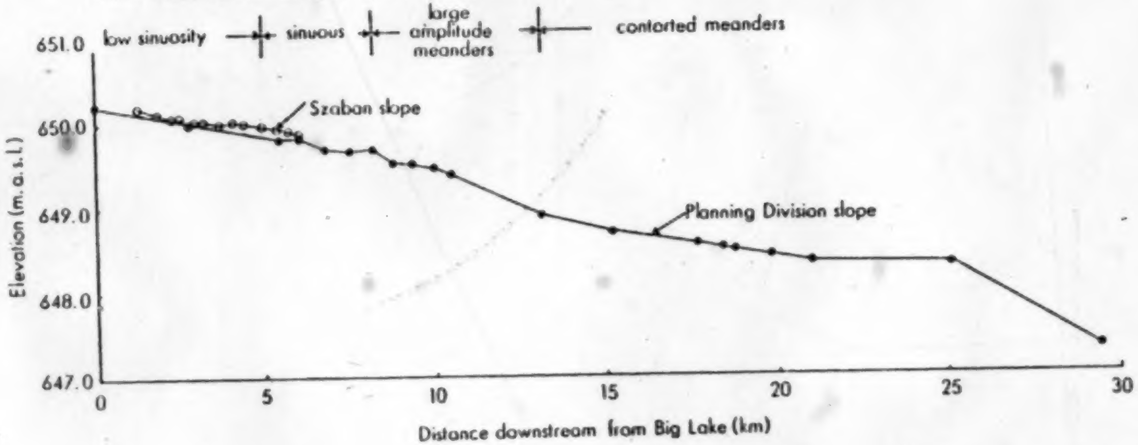


Figure 4.6 Bed and water surface slopes along reaches A to C.

(a) Bed profile from Big Lake to the railroad bridge (Yaremko, 1968).



(b) Water surface slopes from Szabon (1975) and the Alberta Planning Division (unpub.).



of the effect of dredging is unknown, although it may account for this rise. However, the very low channel slope in the upstream portion is natural, i.e. the result of the low valley slope.

The slope (Figure 4.6b) for the portion from cross-section 1 to 8 is 0.0000416 (Szabon, 1975). The channel slope for the portion from cross-section 8 to cross-section 16 is 0.000078, when the data from Szabon (1975) and from Alberta Planning Division (unpub.) (Figure 4.6b) are averaged. The valley slope for cross-sections 1 to 8 is 0.0000424. The valley slope for cross-sections 8 to 16, averaging the Szabon and Alberta Planning Division data, is 0.000086.

Thus, the valley slopes are only slightly greater than the channel slopes for this reach. Schumm and Khan (1972) postulated that a channel alters its pattern to provide a uniform channel slope when the valley slope changes downstream. This is not true for Reach A where the both the channel and valley slope increase with distance downstream.

Ackers and Charlton (1970b) showed that, for laboratory streams in sand, there appears to be a threshold slope between straight channels at very low slopes and meandering channels at higher slopes. This agrees with field observations by Lane (1957) and Morton and Donaldson (1978), as well as with laboratory investigations by Schumm and Khan (1971, 1972) and Friedkin (1945). Morton and Donaldson (1978) generalised findings for suspended load systems

(Figure 4.7). Their example is a deltaic system wherein the slope becomes negative near the mouth. At extremely low slopes, the width to depth ratio tends to be very large. This ratio rapidly decreases to near minimum values between 10 and 15 with only a small increase in channel slope. Sinuosity also rapidly increases from straight at very low slopes to tortuous at low slopes. At maximum sinuosities, minimum width to depth ratios are attained.

This agrees with trends along the Sturgeon River downstream from Big Lake. Initially the width to depth ratio is very large (Table 4.5), but it rapidly decreases towards St Albert with what is probably a very small increase in channel slope. Perhaps a downstream increase in slope from Big Lake provides the channel with sufficient power to erode a more efficient channel form (Rubey, 1952) with well-defined banks. Further downstream, higher sinuosities and smaller width to depth ratios are achieved in reaches B and C where the water surface slope is slightly steeper.

The channel slope of the Sturgeon River is 0.00016 between cross-section 1 and cross-section 2 (Figure 4.6b). The channel slope is gentler than this in the central portion. To acccount for the change in planform from straight to meandering, Schumm and Khan (1972) hypothesised that the increase in slope also increases the effectiveness of the helical flow. It may be that the initial steepening of the channel slope from cross-section 1 to 2 is sufficient to induce helical flow which persists further downstream

Figure 4.7 Generalised diagram of changes in channel characteristics of some suspended load systems (from Morton and Donaldson, 1978, p. 1035, Figure 6).

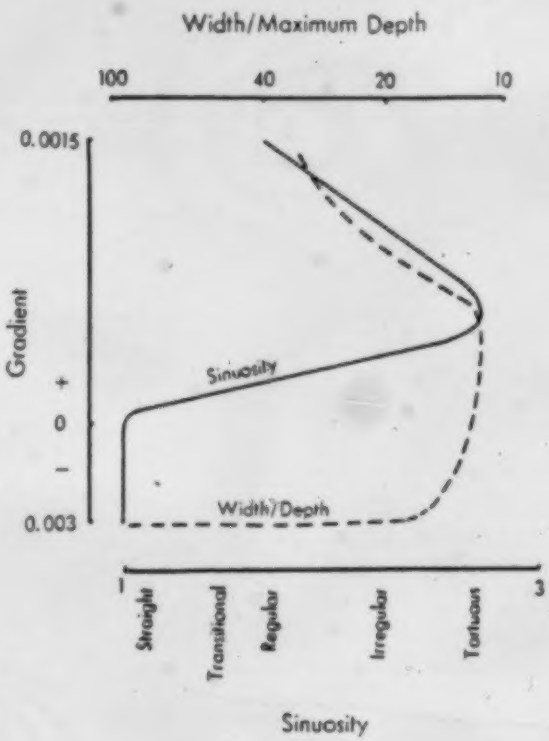


TABLE 4.5. The observed channel width to maximum depth ratio, (W/Dx)o, for Reach A.

Distance Downstream from Big Lake (km)	(W/Dx)o
0.10	363
1.50	69.9
2.68	29.7
2.79	32.7
2.94	33.9
3.33	24.8
3.40	27.1
3.66	25.2
3.76	23.8
4.07	13.8
4.37	24.1
4.67	26.1
4.98	13.6
5.29	16.9
5.59	27.6
6.06	31.3
6.39	32.3

despite the subsequent gentler slope and produces the sinuous pattern of the central portion (Figure 4.1). Alternatively, the channel slope at higher discharges may be steeper along this portion. The increases in wavelength and amplitude in the downstream portion of Reach A may be due to the steeper channel slope there.

There are statistically significant downstream increases in the mean bed and bank sediment sizes, MBD and MBK, respectively, (4.2-3, 4.2-4). There are also statistically significant relations between the wavelengths, L, and amplitudes, Amp, of the simple and large meanders of Reach A and the mean bed and bank sediment sizes (t=4.047, t=2.126, t=2.818, t=1.992). As the simple and large meander wavelengths and amplitudes increase, the channel perimeter sediments become coarser. Some investigators found that there is a significant relation between meander wavelength and sediment size such that channels with coarser sediments tend to have longer meander wavelengths for a given discharge (Schumm, 1967; Ackers, 1980). Thus, the growth of meander amplitude in the downstream portion of Reach A may be related to a downstream increase in erodibility of the channel perimeter sediments which arises from the downstream decrease in the percent of clay.

In summary, the wide shallow channel which issues from Big Lake has an extremely low slope which prevents it from carving an efficient channel form and from developing strong helical flow and a meandering planform. The steeper channel slope between cross-sections 1 and 2 might induce the meandering pattern seen in the central portion despite the low slope there. Also, the channel slope of the central portion may be steeper at higher, channel forming discharges. The valley and channel slopes increase in the downstream portion as does the sinuosity, as predicted by the Schumm-Khan (1972) relationship (Figure 2.1). This may also be affected by the increasing sediment size towards less cohesive and therefore, more erodible sediments. Meander migration appears to have been predominantly in a downstream rather than lateral direction in the downstream portion. The reasons for the development of the compound pattern are not clear. Along the downstream portion, the channel slope is somewhat steeper, and the channel perimeter sediments are more erodible. These factors may contribute to the development of the larger meanders in the downstream portion. The smaller meanders seem to develop once the arc length of the simple meanders exceeds a certain value. This is perhaps a means of creating a smaller pool spacing, more appropriate to the channel width. This adjustment may be particularly necessary during low flows, when the meander arc lengths of the large meanders are especially large relative to the channel width.

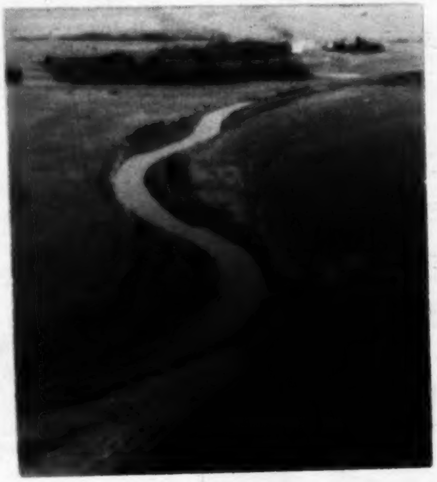
4.3 Reach B

The pattern along Reach B changes from a sinuosity of 1.08 in the upstream portion to a sinuosity of 2.68 in the downstream portion, where there are large amplitude meanders (Figure 4.1). The whole reach is characterised by a compound meander pattern. The small meanders can be seen only at low flows when the alternate shoals, colonised by emergent aquatic plants, become visible (Figure 4.8). Surface Ia appears to be associated with the small meanders of the compound pattern and occurs only in the downstream portion. There are no statistically significant trends in wavelength, L, or radius of curvature, Rc, and only a very small increase in amplitude, Amp, of the small meanders with distance downstream (4.6-4 to 4.6-6).

Qualitative observations along Reach B indicate that aquatic plants markedly reduce the flow velocity and that the roots of the emergent aquatic plants provide a thick mat which is not easily penetrated. The water surrounding the emergent aquatic plants, and often that around the submersed aquatic plants, is usually nearly stagnant. The growth of this vegetation along the channel margins reduces the area through which water flows. However, these plants must also increase the roughness on the channel banks and it is not known whether their presence increases the velocity by decreasing the cross-sectional area or decreases the velocity by increasing channel boundary roughness. Aquatic plants colonise the alternate shoals associated with the

Figure 4.8 Characteristics of the compound portion of reaches A to C.

(a) The small meanders with alternate bars colonised by emergent aquatic plants. Discharge is approximately 3 cumecs.



(b) The compound meanders at higher discharges, when the alternate bars of the small meanders are submerged. The chutes and oxbow lakes which characterise this portion can also be seen.

TABLE 4.6. Distance downstream from Big Lake, dds, in kilometres regressed on radius of curvature, Rc, wavelength, L, and amplitude, Amp, all in metres.

Ref. No.	Data set	Relation	Exponent	Student's t of exponent	Two-tailed significance of t (%)	Coefficient of determination, r^2	Sample size
1	Reach A, small or simple	dds=f(Rc)	-0.77	-2.52	95	0.39	12
2	"	dds=f(L)	-0.14	-0.28	< 50	0.008	12
3	"	dds=f(Amp)	0.08	0.46	<50	0.02	12
4	Reach B, small	dds=f(Rc)	0.01	0.22	<50	0.003	18
5	"	dds=f(L)	0.07	0.99	50	0.06	18
6	"	dds=f(Amp)	0.08	1.52	80	0.13	18
7	Reach C, small or simple	dds=f(Rc)	-0.09	-2.77	99	0.15	46
8	"	dds=f(L)	-0.12	-2.55	98	0.13	46
9	"	dds=f(Amp)	-0.0003	-0.01	<50	0.000002	46
10	Reach D, natural	dds=f(Rc)	-0.003	-1.19	50	0.04	34
11	"	dds=f(L)	-0.002	-0.78	50	0.02	34
12	"	dds=f(Amp)	-0.0004	-0.01	<50	0.0005	34
13	Reach E	dds=f(Rc)	0.02	4.18	99.8	0.41	27
14	"	dds=f(L)	0.03	4.60	99.8	0.46	27
15	"	dds=f(Amp)	0.01	1.50	80	0.08	27
16	Reach F, natural	dds=f(Rc)	0.003	0.71	50	0.02	25
17	"	dds=f(L)	-0.002	-0.38	<50	0.006	25
18	"	dds=f(Amp)	-0.02	-3.20	99	0.31	25
19	Reaches A to C, small or simple	dds=f(Rc)	-0.44	-6.38	99.8	0.34	76
20	"	dds=f(L)	-0.54	-5.61	99.8	0.30	76

TABLE 4.6, continued:

Ref. No.	Data set	Relation	Exponent	Student's t of exponent	Two-tailed significance of t (%)	Coefficient of determination, r^2	Sample size
21	Reaches A to C, small or simple	dds=f(Amp)	-0.04	-0.41	<50	0.002	76
22	Reach A, large or simple	dds=f(L)	0.49	2.80	95	0.49	10
23	"	dds=f(Amp)	0.27	4.90	99	0.75	10
24	Reach C, large or simple	dds=f(L)	-0.21	-3.57	98	0.72	7
25	"	dds=f(Amp)	-0.07	-1.55	80	0.29	7

small meander pattern (Figure 4.8a). This colonisation of the shoals should promote maintenance of the small pattern by stabilising the shoals, increasing deposition on them through reduction of the flow velocity, and enhancing erosion of the thalweg because the flow is concentrated there (e.g. Stephens *et al.*, 1963; Schumm, 1977).

The downstream increase in amplitude of the large meanders may be due either to more easily erodible sediments or to more erosive flows in the downstream portion.

There are statistically significant downstream decreases in the mean bed, MBD, and bank, MBK, sediment sizes and statistically significant downstream increases in Schumm's M and the percent of silt and clay in the channel bed, %SCBD (4.7-1 to 4.7-4, and Figure 4.9). One should recall that the clay data are extrapolated and, furthermore, the results of the chi-squared tests show that the silty clay sediments are statistically different at a cross-section (see Section 3.4.3). However, the evidence indicates that, if anything, the sediments tend to be more cohesive and so less erodible with distance downstream. Channel slope increases from 0.000078 to 0.00015 along this reach (Szabon, 1975; Alberta Planning Division, unpub.). Thus, channel slope increases and so channel erosivity probably increases with distance downstream.

The observed and first-break-in-slope channel cross-sectional data have no significant trends with distance downstream (4.7-8 to 4.7-19 and Figure 4.10) except

TABLE 4.7. Distance downstream from Big Lake in km regressed on channel perimeter sediment variables and cross-section variables for Reach B.

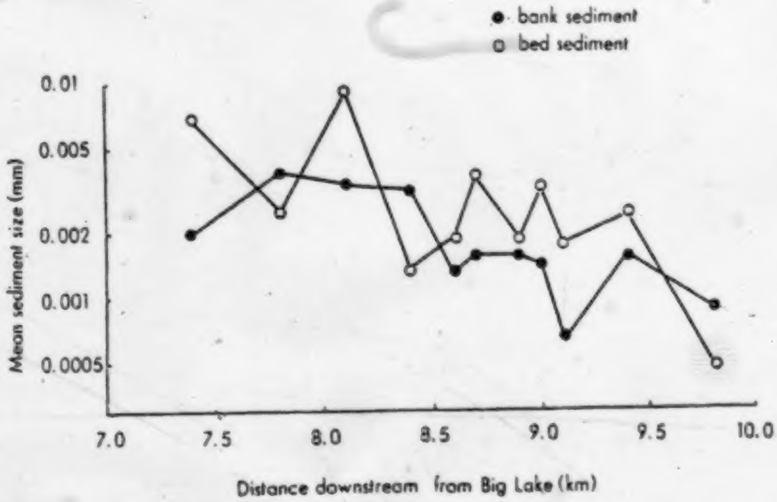
Ref. No.	Regressor	Exponent	Student's t of exponent	Two-tailed significance of t (%)	Coefficient of determination, r^2	Sample size
1	Percent of silt and clay in the channel banks, %SCBK	0.30	0.33	<50	0.01	11
2	Percent of silt & clay in the channel bed, %SCBD	0.23	2.31	95	0.37	11
3	Mean bank sediment size, MBK	-0.10	-2.97	98	0.50	11
4	Mean bed sediment size, MBD	-0.07	-2.87	98	0.48	11
5	Percent of clay in the banks, %CBK	0.52	4.29	99	0.79	7
6	Percent of clay in the bed, %CBD	0.76	5.82	99	0.87	7
7	Schumm's M with observed width & depths, Mo	0.86	6.79	99.8	0.90	7
8	Observed width to max. depth, (W/Dx)o	-0.08	-0.33	<50	0.02	7
9	Observed width to mean depth, (W/Dm)o	0.13	0.47	<50	0.04	7
10	Observed width, Wo	0.29	0.47	<50	0.04	7
11	Max. depth at observed water level, (Dx)o	0.30	0.83	50	0.11	7
12	Mean depth at observed water level, (Dm)o	-0.20	-0.42	<50	0.03	7
13	Observed area, Ao	0.52	0.75	50	0.10	7
14	First-break-in-slope width to max. depth, (W/Dx) fb	-0.15	-0.30	<50	0.04	4
15	First-break-in-slope width to mean depth, (W/Dm) fb	-0.03	-0.06	<50	0.002	4
16	First-break-in-slope width, Wfb	1.54	7.69	98	0.97	4
17	Maximum depth at first-break-in-slope water level, (Dx) fb	0.35	0.97	50	0.32	4
18	Mean depth at first-break-in-slope water level, (Dm) fb	0.34	0.77	<50	0.23	4

TABLE 4.7, continued:

Ref. No.	Regressor	Exponent	Student's t of exponent	Two-tailed significance of t (%)	Coefficient of determination, r^2	Sample size
19	First-break-in-slope area, Afb	0.42	1.60	50	0.56	4
20	Valley-flat break-in-slope width to max. depth, (W/Dx)vf	0.14	0.47	< 50	0.10	4
21	Valley-flat break-in-slope width to mean depth, (W/Dm)vf	0.09	0.64	50	0.17	4
22	Valley-flat break-in-slope width, Wvf	0.02	0.06	<50	0.002	4
23	Max. depth at valley-flat break-in-slope water level, (Dx)vf	-1.21	-2.37	80	0.74	4
24	Mean depth at valley-flat break-in-slope water level, (Dm)vf	-0.27	-1.30	50	0.46	4
25	Valley-flat break-in-slope area, Avf	-0.61	-9.65	98	0.98	4

Figure 4.9 Sediment size characteristics from the channel perimeter of Reach B.

(a) Mean sediment sizes of the bed and bank samples vs distance downstream



(b) Percent of sand and gravel in the bed samples vs distance downstream

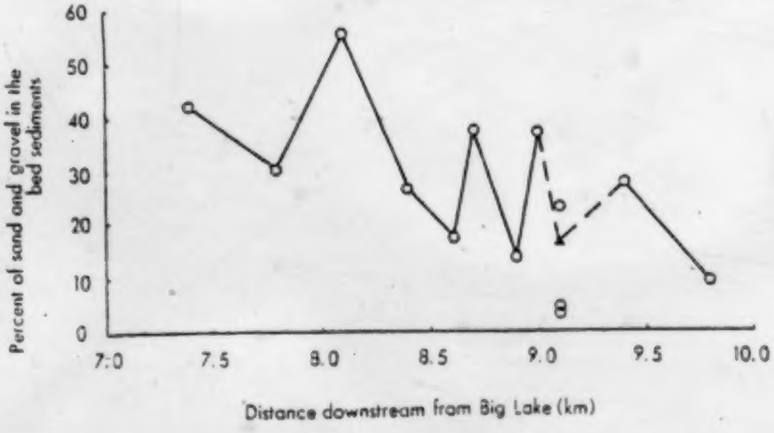
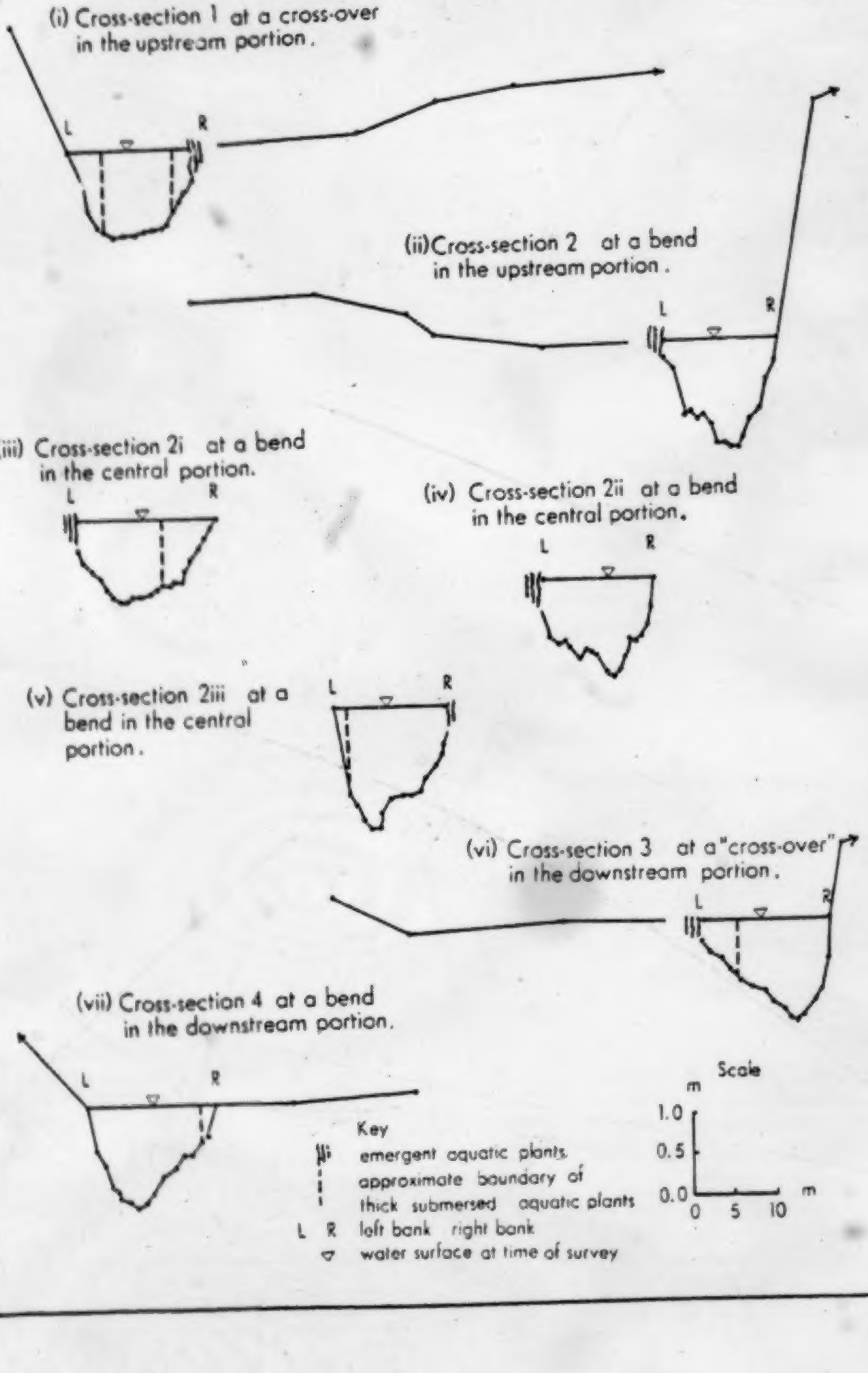


Figure 4.10 Channel cross-sections along Reach B. Cross-section locations are given on Figure 4.1



(i) Cross-section 1 at a cross-over in the upstream portion.

(ii) Cross-section 2 at a bend in the upstream portion.

(iii) Cross-section 2i at a bend in the central portion.

(iv) Cross-section 2ii at a bend in the central portion.

(v) Cross-section 2iii at a bend in the central portion.

(vi) Cross-section 3 at a "cross-over" in the downstream portion.

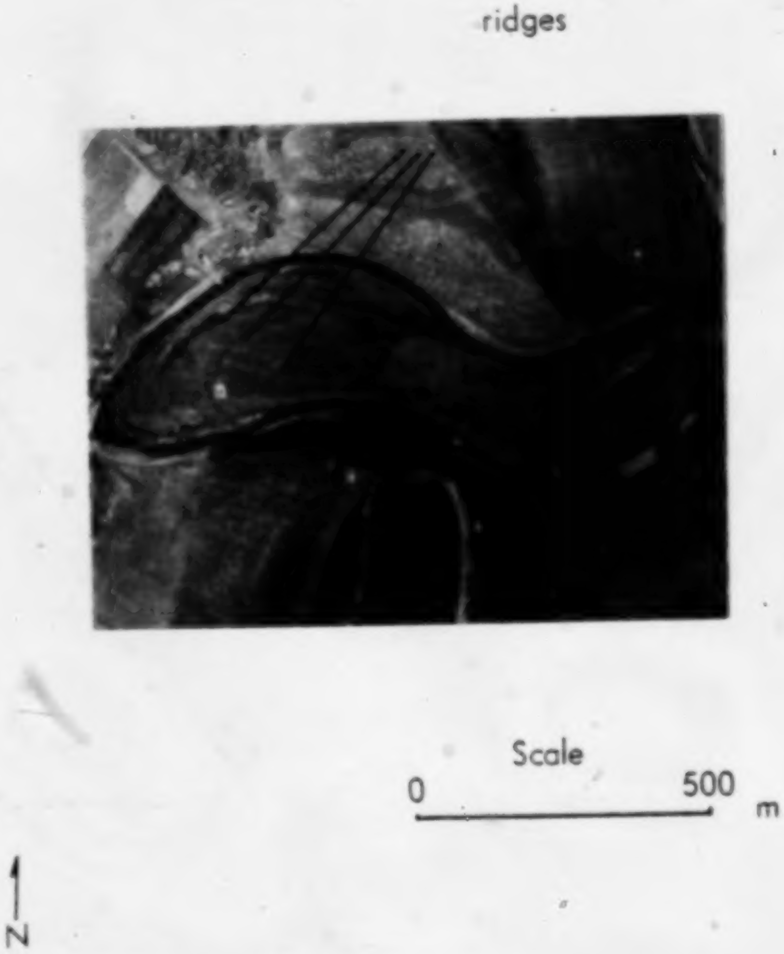
(vii) Cross-section 4 at a bend in the downstream portion.

L
R
Key
emergent aquatic plants
approximate boundary of thick submersed aquatic plants
L R left bank right bank
water surface at time of survey
Scale
m
1.0
0.5
0.0
0
5
10
m

the first-break-in-slope width, Wfb (4.7-16). It should be kept in mind that the first-break-in-slope data have a small sample size. The observed cross-sectional data are approximately equal to the first-break-in-slope cross-sectional data for this reach. As noted, this is the case wherever the compound meandering pattern occurs along reaches A to C. The valley-flat break-in-slope cross-sections are much larger than the first-break-in-slope or observed cross-sections (Table 4.3). These data indicate that the large and small meanders may be adjusted to two quite different formative discharges. However, there is no strong statistical support for this as discussed above, using the data from reaches A to C.

There are three meander cutoffs on the floodplain in the downstream portion. Two of these are still partly connected to the channel and are flooded most of the time (Figure 4.11). The river had cut through the meander necks of these two meanders by 1924 but infilling has been extremely slow. The slow rate of infill indicates that very little bed load is being transported by the channel. Coarser sediments carried as bed load would settle out relatively rapidly on contact with the relatively low velocity flow in the incipient oxbow lake (Table 4.4) and this would result in the infilling of the upstream arm of the oxbow lake. Suspended load settles out more slowly and so the entrance to the oxbow lake remains open to the channel for a much longer period of time.

Figure 4.11 The ridge-depressions of the large amplitude meanders of Reach B.



Very few of the equations for wavelength, L, amplitude, Amp, and radius of curvature, Rc, for the small meanders of Reach B are statistically significant when regressed on the sediment variables (K-5 to K-8, L-5 to L-8, and M-5 to M-8). For the statistically significant equations, the planform variables increase as the sediments become coarser, as predicted by the literature (see Section 2.10).

Because there are only a few large meanders in Reach B, the data for reaches A to C for the large and simple meanders were combined for analysis. For the large or simple meanders, the only statistically significant relations are between amplitude, Amp, and the mean bank sediment size, MBK ($t=-1.96$, 90% sig.), and between the ratio of amplitude to wavelength, (Amp/L), and the mean bank sediment size ($t=-2.508$, 95% sig.) and the percent of silt and clay in the banks, %SCBK ($t=1.714$, 80% sig.). Amplitude and the ratio of amplitude to wavelength both increase as the bank sediments become finer. Generally, the literature leads one to expect that finer sediments are associated with smaller meander dimensions (see Sections 2.10 and 2.11).

The silty-clay sediments in the bed along Reach B occur as small aggregates, about 4 mm in diameter when first removed from the channel bed. Perhaps at high discharges, these sediments are transported as aggregates rather than as discrete particles and so carried as bedload. Therefore, the increase in clay content might mean an increase in bedload which would be associated with longer wavelengths and radii of curvature of the large meanders. However, if it is a bedload channel, one must explain why the oxbow lakes do not fill in more rapidly. Alternatively, it may be incorrect to assume that the large bends of the compound pattern will follow the trends given in the literature for simple meanders.

Perhaps the relatively wide valley in the downstream portion permits the outward growth of meanders and so produces meanders with large amplitudes. Where the valley bottom is widest, the ratio of meander amplitude to meander wavelength for the large meanders is greatest (Table 4.8). For reaches A to C combined, the ratio of amplitude to wavelength for the simple and large meanders is significantly related to the valley bottom width (t=2.984, 99% significance level). Thus, although the initial development of the compound meanders along Reach A does not appear to be associated with the valley bottom width, the occurrence of the large meanders seems to be strongly associated with greater valley bottom widths.

Although the channel perimeter in the upstream portion has a mean sediment size in the silt range, most bed samples have a small proportion of sand and sometimes gravel (Figure 4.9). Therefore, the presence of a scroll bar and a chute (Table 4.4) on each point bar (Figures 4.1 and 4.8b) and the gently sloping point bars (Figure 4.10), which are characteristic of bedload rather than suspended load channels (e.g. Woodyer *et al.*, 1979), are not entirely

TABLE 4.8. The valley bottom width and the ratio of amplitude to wavelength for the large meanders of reaches A, B, and C.

Distance Downstream (km)	Valley Bottom Width (m)	$\frac{\text{Amplitude}}{\text{Wavelength}}$
5.6	72	0.34
6.1	72	0.34
6.3	84	0.38
7.4	84	0.27
7.6	36	0.39
9.9	876	0.71
12.1	816	2.10
12.6	420	0.81

unexpected in the upstream portion, despite the predominantly fine sediment in the channel perimeter.

However, these features are unexpected in the downstream portion where even the bed sediments are very fine (Figure 4.9). In the downstream portion, the scroll bars appear as rows of low amplitude ridges and depressions (Figure 4.11) which are not discernible on the ground. Scroll bars are unusual for a stream with a very high proportion of silt and clay in the channel perimeter. Channel migration of streams in fine sediments is typically very infrequent and takes place by means of avulsion or "stepwise-migration" rather than by "continuous lateral-migration" (Prus-Chacinski, 1971; Taylor and Woodyer, 1978). Prus-Chacinski (1971) stated that alternate shoals which are formed in sandy laboratory channels are typical of non-cohesive sediments, but (p.180) "In a stream running through clay, alternate erosion holes will appear but no transverse alternate shoals". Hence, neither the alternate shoals of the small meanders nor the wide, gently sloping point bars of the large meanders are typical of channels with high proportions of silt and clay in the channel perimeters.

The ridge-depressions may be relict features associated with an earlier phase of the Sturgeon River when the Surface II (Figure 4.1) sands (Bayrock, 1972) provided a source of bed load sediment. The small relief between ridges and depressions could then be explained by the erosion of the ridges and the infilling of the depressions through time. However, these ridge-depressions appear to be associated with the current phase of river activity judging by their close proximity, both vertical and lateral, to the present channel.

Riley and Taylor (1978, p. 91) noted "convex bank deposits that resemble point bars but that are composed of silts and clays". According to Riley (1980, pers. comm.), these point bars have "scroll like" features. Riley postulated that the clay may be transported as flocs rather than as discrete particles and that these flocs are behaving as sands. As noted above, the bed sediments of Reach B are composed of small silty clay aggregates. It may be that the ridge-depressions are the result of bedload transport of these aggregates.

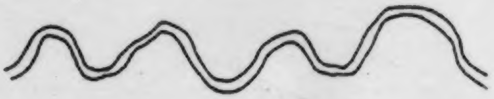
However, the bed sediments in the upstream portion of Reach B and the downstream portion of Reach C are also composed of these silty clay aggregates, and yet there are no ridge-depressions on either of these portions of the Sturgeon River. The finest sediments in reaches B and C occur where the large amplitude meanders exist (see Figures 4.1 and 4.9). Perhaps the effect of the silty clay aggregates predominates in this portion and so produces the unusual features observed there. Also, the steeper channel slope of the large amplitude meander portion may be necessary to provide the stream with enough energy to transport the clay particles as aggregates.

The valley slope also increases in a downstream direction from 0.000086 to 0.0003. Schumm and Khan (1972) observed that sinuosity increases with increasing slope on the laboratory channels in sand up to a threshold slope value where the channel begins to straighten again, and eventually, with increasing slope, the channel braids. Gorycki (1973) studied small laboratory streams flowing on hydrophobic surfaces. He found that, as discharge increases beyond the values necessary to initiate meandering, the channel begins to migrate rapidly and eventually attains wavelength and radius of curvature values which are large relative to the channel width. One can also see (Figure 4.12) that the amplitudes and the ratios of amplitude to wavelength are greater for the rapidly migrating channel. Gorycki postulated that braiding in alluvial channels may result from the inability of non-cohesive sediments to contain such unstable meandering streams. Thus, an increase in stream energy, either by an increase in slope or discharge would produce braiding in non-cohesive sediments; in cohesive sediments it may produce a meandering planform which is large relative to the channel width.

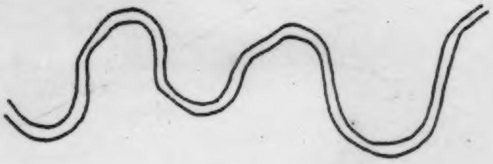
Perhaps the steeper slope of the large amplitude meander portion has produced a pattern similar to that described by Gorycki. The large width of the valley bottom, and the occurrence of rows of ridge-depressions in the downstream portion suggest that lateral and downstream migration is of greater magnitude here than in the river

Figure 4.12 Comparision of sinuous and unstable meanders formed on a hydrophobic surface (from Gorycki, 1973, Figures 5 and 7).

(a) sinuous pattern



(b) unstable pattern, which is produced by increasing water flow beyond that required to induce meandering.



upstream where the valley bottom is narrower and where there is only one scroll bar per point bar. The meanders of the downstream portion of Reach B have large amplitudes and large amplitude to wavelength ratios. However, the ratio of wavelength of the large meanders to the observed channel width is not greater in the large amplitude meander portion than in the portion immediately upstream.

To conclude, various possible explanations have been put forth to explain the downstream changes in the channel planform. The studies by Schumm and Khan (1971, 1972) and Morton and Donaldson (1978) indicate that at low slopes, large changes in pattern can occur with small changes in slope. This is the case through reaches A to C where very small changes in slope are accompanied by large changes in pattern. The results here support the hypothesis that there are slope thresholds for channel patterns of streams in silt and clay. Another alternative is that the downstream valley widening permits the growth of meander amplitude. The ridge-depressions and gently sloping point bars are unusual for channels in fine sediments. They may be relict features or perhaps the result of transportation of the silty clay aggregates as bed load rather than suspended load. The downstream variations in the characteristics of the small meanders are not statistically related to sediment size or cross-sectional characteristics.

4.4 Reach C

The planform of the Reach C (Figure 4.1) changes from large amplitude meanders in the upstream portion to contorted meanders in the downstream portion with a transitional portion in between. The small meander wavelengths, L, and radii of curvature, Rc, have small but statistically significant downstream decreases (4.6-7, 4.6-8). There is no significant downstream change in the amplitude, Amp, of the small meanders (4.6-9). The variation in each of these three planform variables decreases from the upstream to the downstream portion (Table 4.9). Sinuosity is greatest in the upstream portion, (2.68, for all the large amplitude portion), lowest in the central portion (1.92) and intermediate in the downstream portion (2.14). The wavelengths of the simple meanders are generally smaller than those of the small meanders of the compound portion. In fact, there is an overall downstream decrease in the wavelengths, L, of the simple and small meanders from Reach A to Reach C, despite the occurrence of the compound pattern for part of this distance (4.6-19, 4.6-20).

The valley narrows along Reach C in a downstream direction (Table 4.1). Surface Ia (Figure 4.1), the surface associated with the small meanders, gradually dies out in the transitional portion. In the transitional and contorted portions, high steep banks are formed where the river undercuts the valley walls of Glacial Lake Edmonton silts and clays (e.g. 6% sand, 76% silt, 18% clay at sample

TABLE 4.9. Averaged planform data for the Sturgeon River from the downstream portion of Reach B to the downstream portion of Reach C for the simple or small meander data. The planform variables used are radius of curvature, Rc, wavelength, L, and amplitude, Amp.

Sturgeon River Portion	Planform Characteristic	Mean (m)	Standard Deviation
Downstream portion of Reach B and upstream portion of Reach C.	Rc	158	81
	L	380	198
	Amp	93	103
Central portion of Reach C.	Rc	111	76
	L	280	134
	Amp	74	42
Downstream portion of Reach C.	Rc	75	56
	L	209	103
	Amp	67	46

location H, shown on Figure 4.1). The confining effect of the narrow valley in the downstream portion may inhibit the channel's ability to form the large amplitude meanders.

There are no statistically significant downstream changes in the characteristics of the observed cross-sections for Reach C (4.10-8 to 4.10-13). The cross-sections are narrow and deep along the whole reach (Figure 4.13).

The first-break-in-slope width, Wfb, maximum depth, (Dx)fb, and area, Afb, all increase significantly with distance downstream (4.10-16, 4.10-17, 4.10-19). Where the compound pattern occurs, the first-break-in-slope stage is approximately equal to the observed stage (Table 4.3). The first-break-in-slope stage increases downstream until the downstream end of the reach, where the first-break-in-slope stage is equivalent to the valley-flat break-in-slope stage (Table 4.3). As noted above, a first-break-in-slope stage which is approximately equal to the observed stage is typical of the compound pattern.

The channel slope is greatest in the upstream portion where it is 0.00014. In the contorted portion, the channel slope is 0.000033 if the last data point is excluded (Figure 4.6b). The last point occurs after an artificially straightened portion (Alberta Department of Highways, 1968). The straightened reach was shortened in 1969-1970 from 418 m to 195 m. If the channel slope is recalculated, adding the extra 223 m, the natural slope for the whole contorted

TABLE 4.10. Distance downstream from Big Lake in km regressed on channel perimeter sediment variables and cross-section variables for Reach C.

Ref. No.	Regressor	Exponent	Student's t of exponent	Two-tailed significance of t (%)	Coefficient of determination, r^2	Sample size
1	Percent of silt and clay in the channel banks, %SCBK	-0.38	-1.78	90	0.18	16
2	Percent of silt and clay in the channel bed, %SCBD	-0.19	-1.25	50	0.10	16
3	Mean bank sediment size, MBK	0.09	5.29	99.8	0.67	16
4	Mean bed sediment size, MBD	0.05	3.09	99	0.40	16
5	Percent of clay in banks, %CBK	-0.64	-5.28	99.8	0.82	16
6	Percent of clay in the bed, %CBD	-0.66	-2.45	95	0.50	16
7	Schumm's M using observed widths and depths, Mo	-0.17	-1.61	80	0.30	8
8	Observed width to max. depth ratio, (W/Dx)o	-0.30	-1.41	50	0.25	8
9	Observed width to mean depth ratio, (W/Dm)o	-0.43	-1.36	50	0.24	8
10	Observed width, Wo	-0.51	-1.00	50	0.14	8
11	Max. depth at observed water level, (Dx)o	0.31	1.12	50	0.17	8
12	Mean depth at observed water level, (Dm)o	0.30	0.69	< 50	0.07	8
13	Observed area, Ao	0.002	0.006	< 50	0.00005	8
14	First-break-in-slope width to max. depth ratio, (W/Dx)fb	-0.30	-2.56	90	0.69	5
15	First-break-in-slope width to mean depth ratio, (W/Dm)fb	-0.40	-3.38	95	0.79	5
16	First-break-in-slope width, Wfb	0.42	1.79	80	0.52	5
17	Max. depth at first-break-in-slope water level (Dx)fb	0.26	6.11	99	0.93	5

TABLE 4.10, continued:

Ref. No.	Regressor	Exponent	Student's t of exponent	Two-tailed significance of t (%)	Coefficient of determination, r^2	Sample size
18	Mean depth at the first-break-in-slope water level, (Dm)fb	0.35	12.59	99.8	0.98	5
19	First-break-in-slope area, Afb	0.23	5.55	98	0.91	5
20	Valley-flat break-in-slope width to max. depth ratio, (W/Dx)vf	-0.20	-2.02	80	0.58	5
21	Valley-flat break-in-slope width to mean depth ratio, (W/Dm)vf	-0.13	-1.32	50	0.37	5
22	Valley-flat break-in-slope width, Wvf	-0.30	-1.90	80	0.55	5
23	Max. depth at valley-flat break-in-slope water level, (Dx)vf	0.51	1.88	80	0.54	5
24	Mean depth at valley-flat break-in-slope water level, (Dm)vf	0.21	1.05	50	0.27	5
25	Valley-flat break-in-slope area, Avf	-0.39	-0.94	50	0.23	5

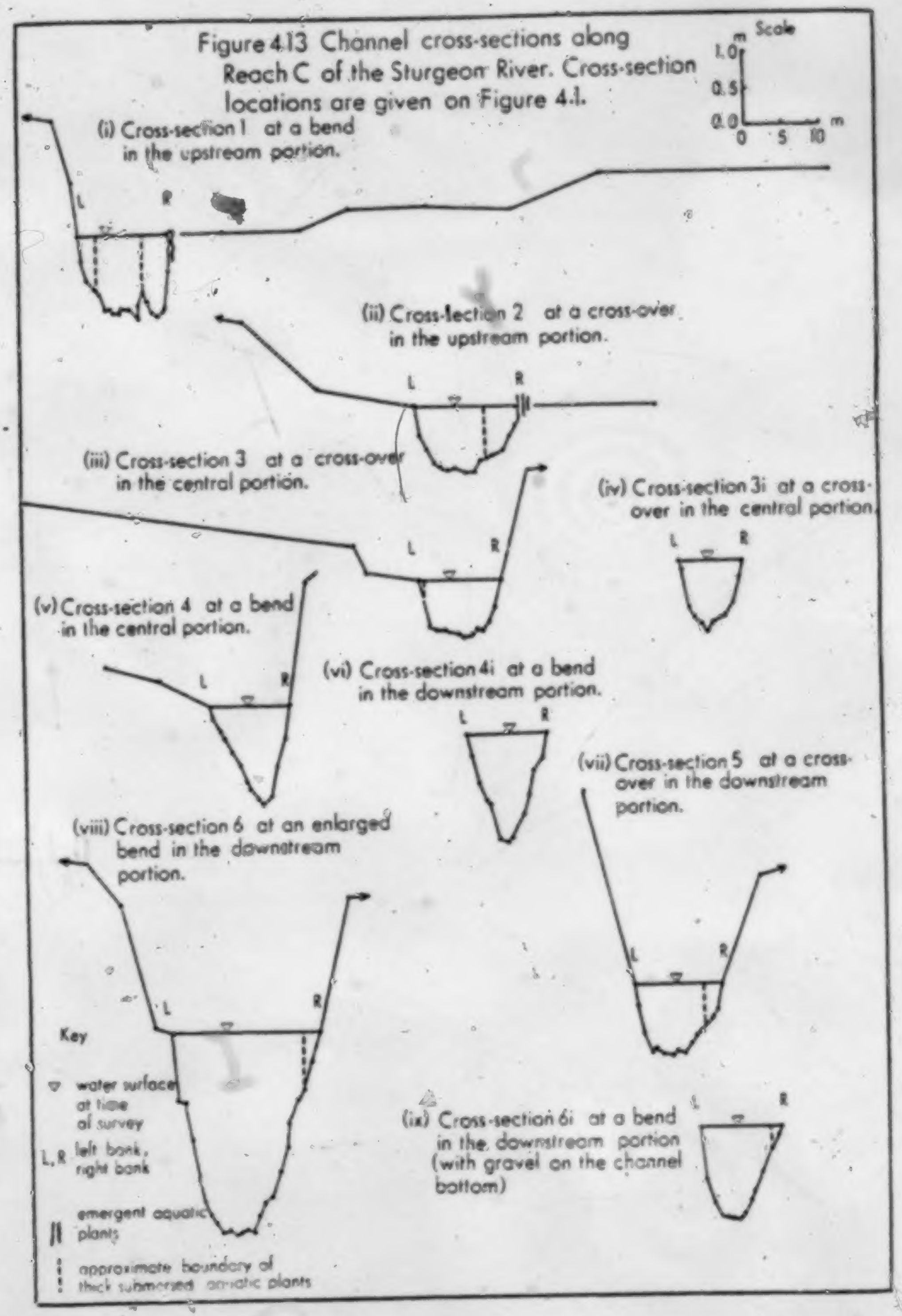


Figure 4.13 Channel cross-sections along Reach C of the Sturgeon River. Cross-section locations are given on Figure 4.1.

Scale
m
1.0
0.5
0.0
0
5
10
m
(i) Cross-section 1 at a bend in the upstream portion.
L
R
(ii) Cross-section 2 at a cross-over in the upstream portion.
L
R
(iii) Cross-section 3 at a cross-over in the central portion.
L
R
(iv) Cross-section 3i at a cross-over in the central portion.
L
R
(v) Cross-section 4 at a bend in the central portion.
L
R
(vi) Cross-section 4i at a bend in the downstream portion.
L
R
(vii) Cross-section 5 at a cross-over in the downstream portion.
L
R
(viii) Cross-section 6 at an enlarged bend in the downstream portion.
L
R
(ix) Cross-section 6i at a bend in the downstream portion (with gravel on the channel bottom)
L
R
Key
▽ water surface at time of survey
L, R left bank, right bank
emergent aquatic plants
approximate boundary of thick submersed aquatic plants

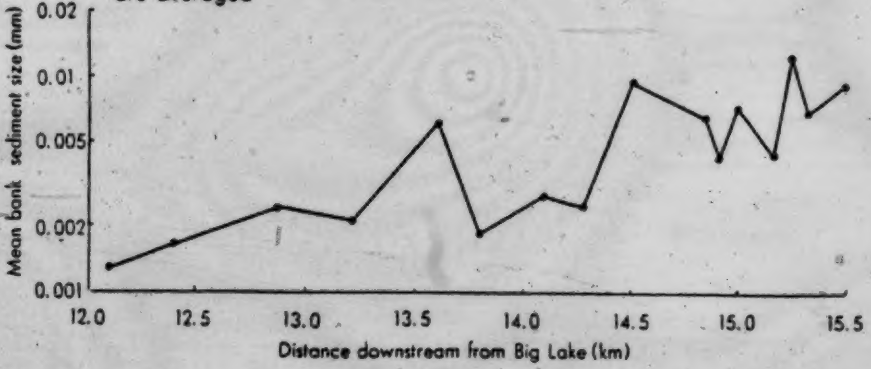
portion becomes 0.000106. There is only one water surface data point for the transitional portion: the channel slope from the end of the large amplitude meander portion to the middle of the transitional portion is 0.000139; the channel slope from the transitional portion to the beginning of the contorted portion is 0.000057. The valley slope for the large amplitude meander portion is 0.0003 and 0.00026 for the contorted portion. Thus, the water surface slope and the valley slope decrease slightly from the large amplitude meander portion to the contorted portion.

With increasing distance downstream (Figure 4.14), there is a small but statistically significant increase in the mean bed and bank sediment sizes, MBD and MBK, from clay to silt (4.10-3, 4.10-4), a highly significant downstream decrease in the percent of clay, %CBK and %CBD (4.10-5, 4.10-6) and a significant decrease in the percent of silt and clay in the channel banks, %SCBK(4.10-1). Because the variation is within the silt-clay range, the per cent silt-clay bed sediment data and Schumm's M have poorer statistical relations with distance downstream (4.10-2, 4.10-7). Unfortunately, the sediment was not sampled to the end of the downstream portion. The bed sediments continue to be silty-clay aggregates with the exception of a gravel riffle between cross-sections 6 and 6i.

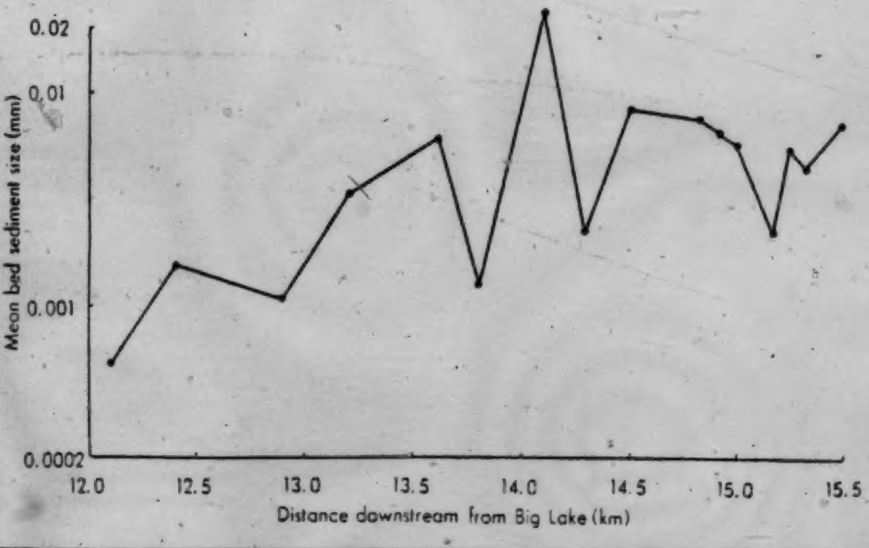
The contorted portion of Reach C is in many ways typical of suspended load channels with very low slopes which flow through fine sediments. It has a tortuous channel

Figure 4.14 Sediment size characteristics from the channel perimeter of Reach C.

(a) Mean sediment sizes of the bank samples vs distance downstream for Reach C. Left and right bank samples are averaged



(b) Mean sediment sizes of the bed samples vs distance downstream for Reach C. The relatively coarse mean size of the sample at 14.11 km results from the presence of root casts in the sample.



pattern, narrow and deep cross-sections, steep convex banks and lacks scroll bars (e.g. Lane, 1957; Riley, 1975; Woodyer *et al.*, 1979).

Possibly, the large amplitude meander pattern is associated with bedload transport of the clay aggregates while the contorted pattern is associated with suspended load transport of silty sediments. As discussed above, for the large or simple meanders of reaches A to C, amplitude and amplitude:wavelength increase as the sediment size decreases.

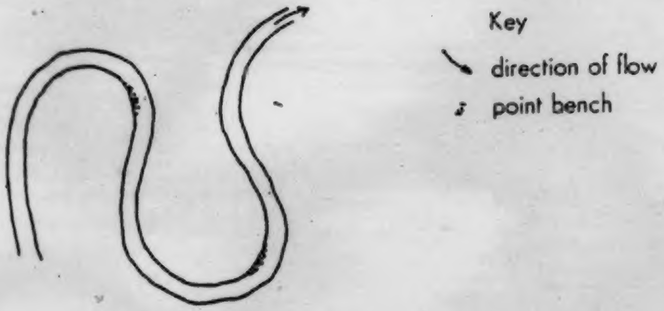
The large or simple meander amplitudes, Amp, and wavelengths, L, are not strongly related to the cross-sectional variables (t has 50% or lower significance in all cases). Associated with the downstream change in the channel pattern is a downstream change in the form of the inside banks of bends. The point bars in the large amplitude meander portion are wide and gently sloping; in the transitional portion, the point bars are smaller and somewhat steeper; and in the downstream portion, the inside banks are almost as steep as the outside banks of bends (Figure 4.13). Although the bend at cross-section 6 is unusually wide and deep, the shape of the inside bank is typical of other inside banks of bends in the contorted portion. The unusually wide and deep bends, such as that at cross-section 6, are here referred to as "enlarged bends" and are discussed below (Section 4.5).

In the downstream portion of Reach C, small mud bars are visible near or just above water level (when water discharge is near 2 cumecs). They occur along the inside banks of most bends, beginning near the meander apices and continue along the inside banks on the downstream side of the meander lobe (Figure 4.15). The small mud bars along the inside banks of bends are thought to be inchannel benches, called "point benches" by Woodyer *et al.*, (1979). Aquatic plants were not well established on these benches at the time of observation. Since these plants grow thickly on most shallow, stable channel deposits, their sparse occurrence on the point benches suggests that these benches are temporary features which are activated at higher stages.

The maximum velocity thread moves from the outside bank to the inside bank as the bends become tight (Rozovskii, 1961; Hickin, 1978). Hence, for very tight bends, the shear stress is high over the point bar and, therefore, deposition here is limited. In the downstream portion of Reach C, the radii of curvature are often small. It appears that the shear stress along the inside banks of the bends is great enough to transport the predominantly silt and clay load along the inside bank until the apex or just downstream of the apex at low flows and perhaps erode the point benches at higher flows. Thus, the meander points are steeply sloped.

The point benches are possibly the result of flow separation along the convex bank. According to Rozovskii (1961, p. 117), where pressure increases rapidly along the

Figure 4.15 Sketch of point benches, found where the channel pattern is contorted.



flow then "fluid layers braked by the wall, have insufficient energy to overcome it. These layers having exhausted their reserve of kinetic energy, turn in the opposite direction". In other words, an area of reverse flow, i.e. a zone of separation, is set up along the bank. The water surface contours of a tight bend (Figure 4.16) show that there is a great difference in the water surface height at the bend apex between the inside bank and the outside bank. This is the result of the great strength of centrifugal force at the tight bend because of the small radius of curvature (see Section 2.8). The rapid increase in the water surface elevation along the outside wall downstream towards the bend apex means that there exists a downstream increase in pressure. Similarly, along the inside bank, the increase in the water surface elevation from the bend apex to the bend exit leads to a downstream increase in pressure at the bend exit. These rapid increases in pressure result in separation zones in these two places along the banks of tight bends (Figure 4.16). Rozovskii found that the formation of separation zones also depends on the effect of the side walls on flow. Where the flow is deeper and the bank slopes gentler, the influence of bank friction will be greater and so the possibility of separation zones forming is greater. In these areas of reversed flow, the stream velocity declines and sediment is deposited from the flow to form point benches or concave bank benches (Hickin, 1978, Woodyer *et al.*, 1979). Along the Sturgeon River, the point

Figure 4.16a Locations of possible formation of separation zones along a bend, shown in plan. (Rozovskii, 1961, p. 5, Figure 3).

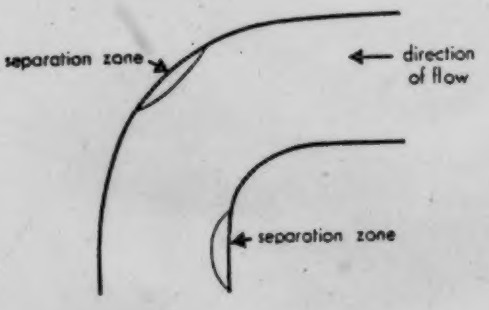
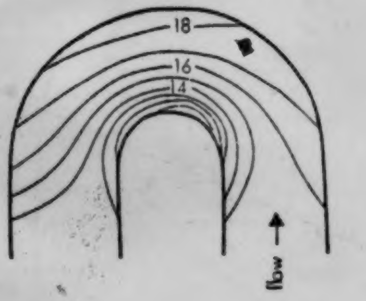


Figure 4.16b Plan view of a tight bend, showing the water surface contours in millimetres (Rozovskii, 1961, p. 116, Figure 44).

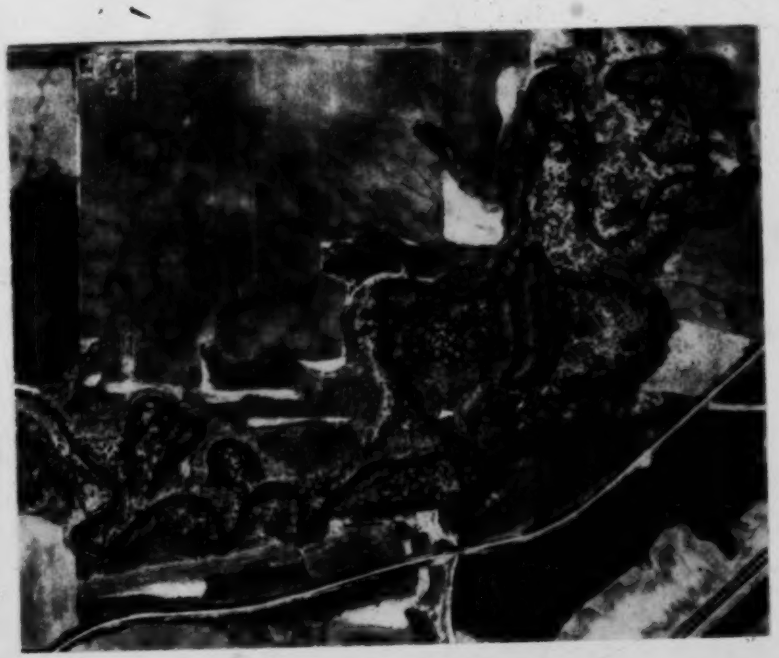


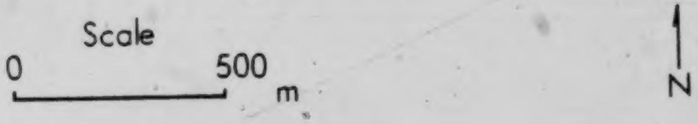
benches are much more common than are concave bank benches. This is probably because the inside banks are usually more gently sloping than the outside banks (Figure 4.13) and so the formation of separation zones is easier. In fact, in the contorted portion, concave bank benches were observed only at some of the enlarged bends.

The minimal deposition on the inside banks of bends will inhibit lateral meander migration. The ability of the channel to erode its outside banks does permit the lateral and downstream migration of the outside banks but this eventually must be limited by the development of concave bank separation zones and the formation of cutoffs.

The absence of scroll bars (Figure 4.1), the frequent occurrence of meander cutoffs (Figure 4.17), and the steep inside banks of bends of the contorted portion all indicate that avulsion is more important than gradual lateral and downstream migration of the meander form. Riley and Taylor (1978) and Taylor and Woodyer (1978) proposed that channel avulsion is one of the major causes of channel shifting in the suspended-load Barwon River. They proposed a number of means by which avulsion could occur. One method is the growth of inchannel benches and debris or vegetation clogs which can constrict the channel and so cause avulsion. Vegetation clogs along the Sturgeon River could develop when plants grow along the channel perimeter during low flows, and debris clogs could result from beaver lodges and dams. No inchannel benches observed along this reach appeared to

Figure 4.17 Cutoffs in the contorted portion of Reach C.





be large enough for channel constriction.

Although it does seem likely that the Sturgeon River moves by avulsion in this portion, avulsion has not occurred in the time covered by the air photographs of Reach C. Taylor (1980, pers. comm.) postulated that avulsion is a long term process taking hundreds or thousands of years and so these changes may not be observable over such a short period of time.

To summarise, the downstream portion of Reach C has a contorted channel pattern, as one would expect from the literature concerning low slope - suspended load streams. Also in common with other tortuous channels described in the literature, are the steep convex banks, many cutoffs, and the absence of scroll bars. These features indicate that the channel is characterised by avulsion. The many tight bends along the contorted portion produce flow separation zones where inchannel benches are deposited. As discussed in Reach B, the downstream disappearance of the large amplitude meanders and the compound pattern may result from the decreasing valley width with distance downstream, the small reduction in slope, and from the introduction of silty sediments into the load. Although the change from large amplitude meanders to contorted meanders is associated with a downstream valley narrowing, the Sturgeon Valley widens between reaches C and D and yet the pattern remains contorted. The central portion of the reach has some characteristics intermediate between the two reaches and is regarded as transitional between the two patterns.

4.5 Enlarged Bends

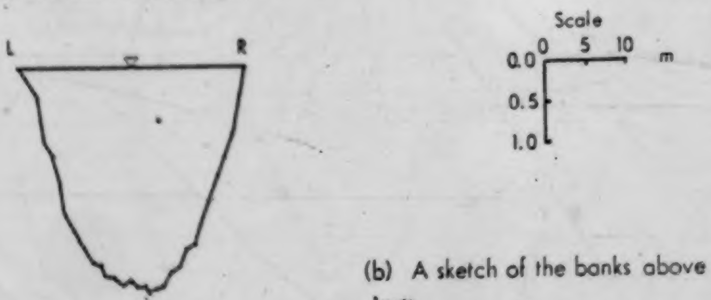
Enlarged bends occur frequently in the contorted portions of the Sturgeon River. The channel cross-sections at these bends (Figures 4.13, 4.23 and 4.18) are much wider and deeper than at other bends in these portions. No quantitative definition was made to differentiate these enlarged bends from the other bends. The great widths result in unusually small values of the ratio of the radius of curvature to the first-break-in-slope width (e.g. 0.77, 0.78). Also, many of the enlarged bends have concave bank benches.

Several investigations have been made concerning enlarged bends and concave bank benches. Hickin (1978, 1979) observed concave bank benches which form at and just upstream of the apices of tight bends along the Squamish River. These benches are composed of sediment much finer than that on the channel bed and coincide exactly with the observed zones of reversed flow.

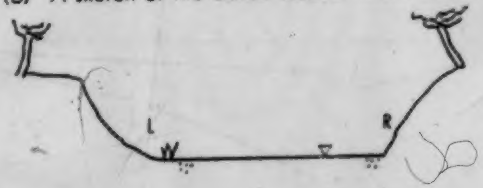
Carey (1969) discussed abrupt angle bends along the Mississippi River. These bends occur where the channel direction is changed abruptly by impingement upon an erosion resistant wall. Carey stated that a large eddy forms along the concave bank just upstream of the point of impingement. The eddy deposits fine sediments in a bar which eventually

Figure 4.18 An enlarged bend between Reach C and Reach D, in the contorted portion of the Sturgeon River.

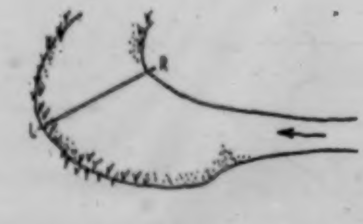
(a) The bend cross-section.



(b) A sketch of the banks above water level.



(c) A sketch of the planform of the bend.



Key

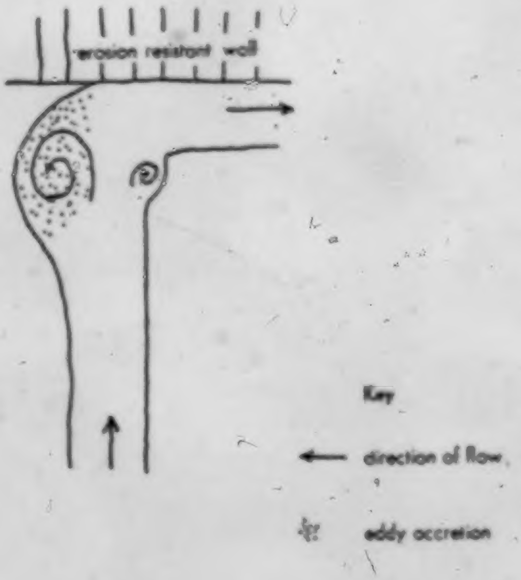
W	emergent aquatic plants
⁘	submersed aquatic plants
▽	water surface at time of survey
←	direction of flow
L, R	left bank, right bank

joins with the mainland as the entire configuration migrates downstream along the valley wall (Figure 4.19). A "dead water zone" is left behind by the downstream passage of the pool and this provides room for eddy accretion to take place. The largest channel depths form at these abrupt angle bends.

Baker (1978) discussed the Rio Jurua of Brazil which is characterised by unusually wide meander bends. This river has a relatively narrow floodplain, high sinuosity, banks stabilised by vegetation and cohesive sediment, no scroll bars, and frequent cutoffs. Tricart (1977, from Baker 1978) postulated that the development of the wide bends is the result of the outside banks retreating faster than point bar deposition can advance the inside banks. The limited amount of deposition on the point bar is due to the small amount of bedload in the channel, according to Tricart.

Woodyer (1970, 1975) and Woodyer *et al.* (1979) described concave bank benches on the Barwon River. The Barwon River is a low slope, high sinuosity, suspended load channel which shows no evidence of downstream channel migration. It has a narrow valley and the stream frequently impinges upon the valley walls which are often composed of resistant material. Woodyer (1970) noted that not all tight bends along his study reach have concave bank benches. Those that do have a rapid widening upstream of the bend, related to an upstream eddy. Woodyer (1975) postulated that these bends only form where channel expansion occurs because of

Figure 4.19 Abrupt-angle eddy formation.
(from Carey, 1969, p. 985, Figure 3).



some special circumstance, for example where cutoffs join the channel. This provides the space for eddy accretion which is otherwise not available because the Barwon River does not migrate downstream as the Mississippi River does.

To summarise, these enlarged bends and concave bank benches occur along streams with a high proportion of suspended load, banks of cohesive material, and narrow floodplains. The narrow floodplains promote the development of abrupt angle eddy formation. The fine sediments allow the development of tight bends because the cohesive sediments usually discourage chute formation, according to Tricart (1977). Also, the fine sediment load is not deposited out as quickly as coarser particles so that, if the shear stress is high along the inside bank, as it is for tight bends (see the Reach C discussion), then deposition will be limited along the inside bank which, in turn, limits the lateral advance of the point bar. However, concave bank benches can form in channels with coarser sediment loads (e.g. the Squamish River) if tight bends can form.

At most of the enlarged bends along the Sturgeon River, there were small bars along the concave bank near water level when the discharge was about 2 cumecs. These bars were usually colonised by aquatic plants. What was thought to be a concave bank bench above water level was seen at only one location.

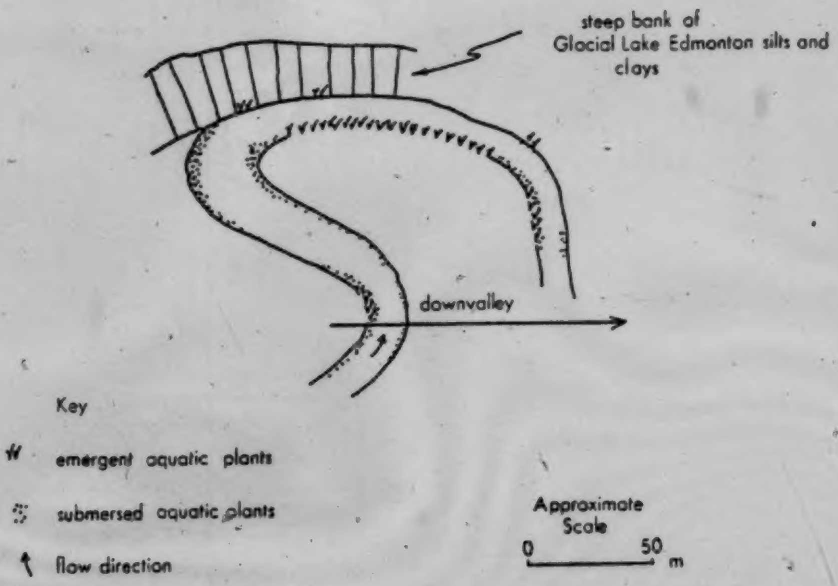
At some enlarged bends, the channel is impinging on the valley walls, which in many cases, are composed of Glacial

Lake Edmonton silts and clays. For the example shown (Figure 4.20), the channel is flowing towards the valley wall at an angle greater than 90°. Just upstream of the impingement, the channel widens along the outside bank. The aquatic plants along this bank indicate the presence of a shallow bar, a concave bank bench. There is a point bench along the inside bank. In this case, the enlarged bend may be explained by abrupt angle eddy formation. The channel in the contorted portion of the Sturgeon River does not seem to be migrating downstream. This raises the question as to how the space for flow reversal and eddy accretion has been created. Perhaps the high angle of impingement encourages reverse flow to the degree that this flow is strong enough to erode the outside wall upstream of the bend at high discharges (e.g. Woodyer, 1970).

At some enlarged bends the river is undercutting the valley walls by eroding a sandy layer underlying the Glacial Lake Edmonton silts and clays. At other bends, the channel is eroding bedrock which underlies the Glacial Lake Edmonton sediments. In yet other cases, the enlarged bends are not impinging on the valley walls

Although the river in the contorted portions is not rapidly migrating downstream, it does not appear necessary to have the special conditions proposed by Woodyer to provide the space for flow reversal. In the bends observed, no such special conditions could be seen, although perhaps they existed but have become obscured through concave bank

Figure 4.20 A sketch of an enlarged bend between Reach C and Reach D, in the contorted portion of the Sturgeon River. The flow is impinging on the valley walls.



deposition.

The unusually small ratios of radius of curvature to width, as well as the great depths of these bends provide the conditions favourable for the development of the concave bank separation zones (Rozovskii, 1961). Perhaps at some critical value of radius of curvature:width, possibly in association with an upvalley flow direction, the flow reversal along the outside bank is strong enough at high discharges to erode the outside wall at and just upstream of the bend's apex. At lower flows, a weaker flow reversal occurs in the widened area and the reversed flow deposits a concave bank bench. The small amount of coarse load and the high flow velocities along the inside banks of tight bends reduce deposition on the point and, therefore, prevent the lateral advance of the point. Consequently, the bends become unusually wide. The great depth of these bends is probably the result of the very great strength of the downward flow component due to strong secondary circulation.

4.6 Reach D

Before 1962-63, the Sturgeon River had a contorted channel pattern along Reach D (Figure 4.21) with a sinuosity of 1.92. The central portion was straightened in 1962-63 (Alberta Department of Highways, 1962) by creating five cutoffs (Figure 4.22). The straightened portion now has a sinuosity of 1.17. Unfortunately, very little information is

Figure 4.21 The Sturgeon River along Reach D.

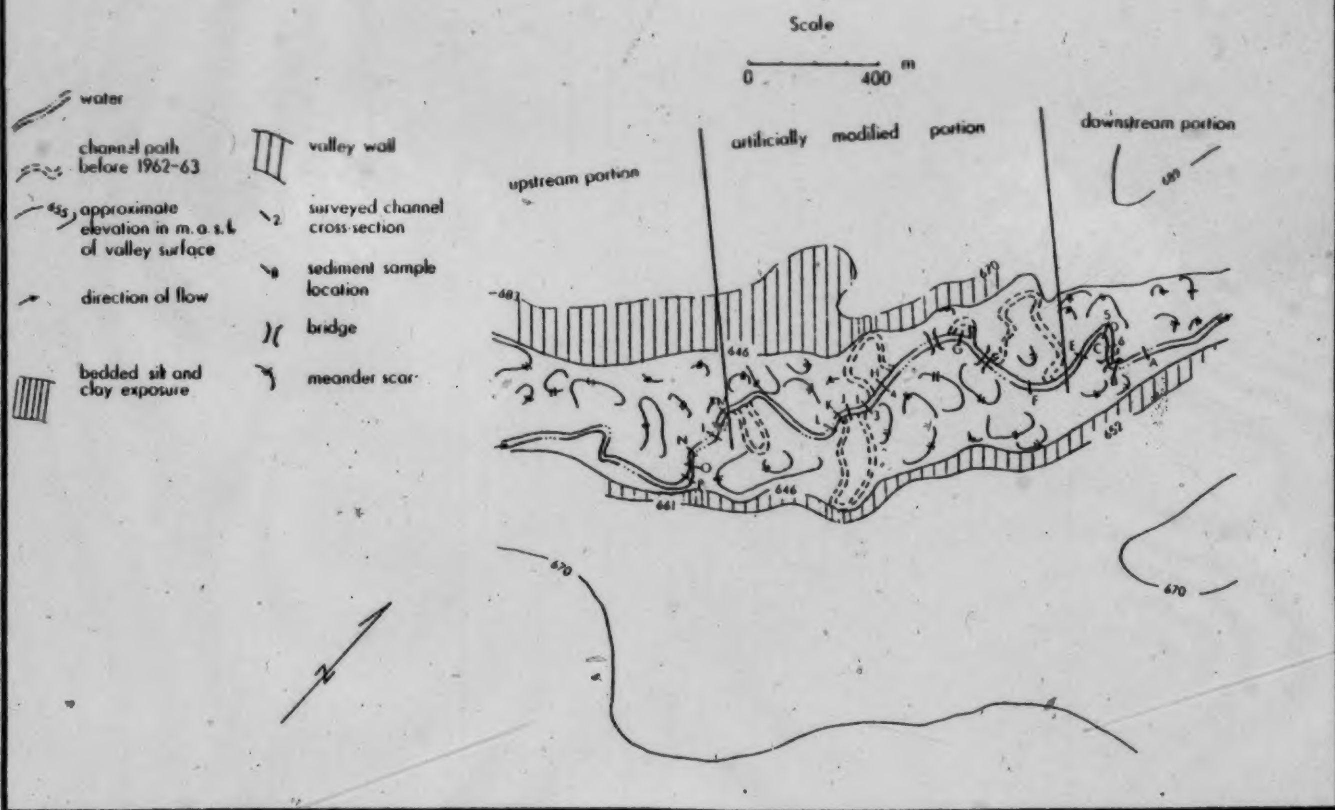
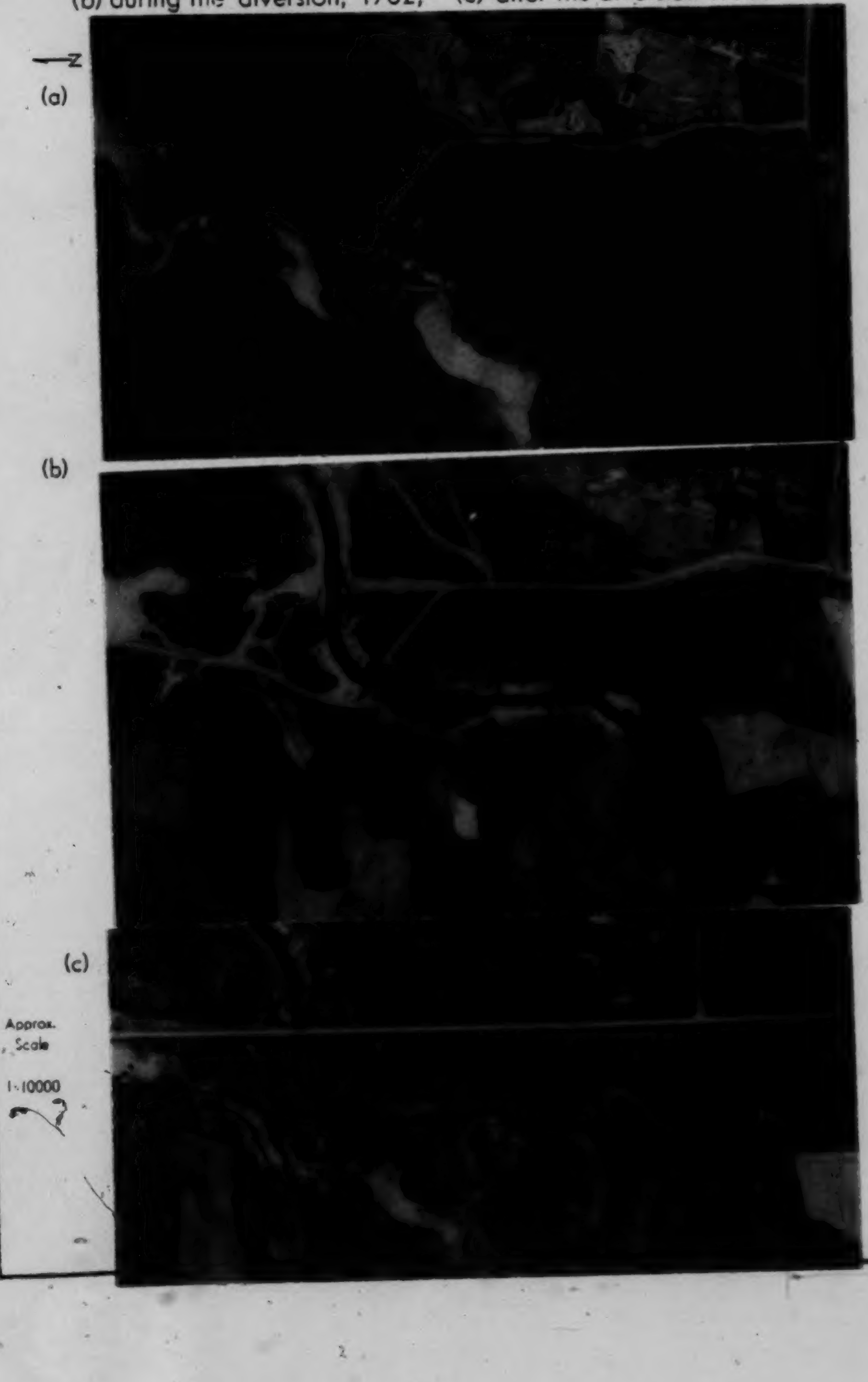

Scale
0
400
m
water
channel path before 1962–63
655 approximate elevation in m.a.s.l. of valley surface
direction of flow
bedded silt and clay exposure
valley wall
surveyed channel cross-section
sediment sample location
bridge
meander scar
upstream portion
artificially modified portion
downstream portion
683
646
670
661
646
652
670
670
N

Figure 4.22 Reach D (a) before the diversion, 1924; (b) during the diversion, 1962; (c) after the diversion 1976.



available on the diversion work done in this portion, or on the characteristics of the prediversion reach (Shalagan, pers. comm., 1980). The prediversion wavelength, L, radius of curvature, Rc, and amplitude, Amp, show no significant downstream trends (4.6-10 to 4.6-12). The mean values of radius of curvature and wavelength are very small for the natural pattern, being 61 and 151, respectively. These means are similar to but smaller than those for the downstream portion of Reach C which also has a contorted pattern (Table 4.9). The channelised portion of Reach D has longer and gentler bends but amplitudes which are similar to those of the natural pattern.

Bayrock (1972) indicated that this portion of the Sturgeon River occupies a valley excavated by a "meltwater channel". The valley bottom widths are fairly uniform along Reach D (Table 4.11). There are no terraces above the valley bottom surface (Figure 4.21). There are meander scars across the entire valley bottom (Figure 4.21). Before the channel was straightened, the river undercut the valley walls in several places. Thus, it appears that the channel has moved across the entire valley floor, removing any evidence of earlier alluvial surfaces.

The first-break-in-slope stage of the channel cross-section occurs near or at the valley-flat break-in-slope stage, as is the case for the downstream portion of Reach C (Table 4.3). The only statistically significant downstream changes in the first-break-in-slope

TABLE 4.11. Valley bottom widths along Reach D.

Distance Downstream (km)	Valley Bottom Widths (m)
53.3	420
53.4	432
53.6	432
53.9	444
54.1	456
54.1	420
54.3	408
54.4	432
54.6	468
54.7	492
55.1	372
55.2	348

data are in width, Wfb, maximum depth, (Dx)fb, and area, Afb, all of which have very small exponents (4.12-11 to 4.12-16).

The prediversion channel slope, 0.00021, was measured from a 1:12000 topographic map and is not considered to be very accurate. The valley slope for this reach is 0.00044. Sinuosity is equal to the valley slope divided by the channel slope. Solving for the channel slope of the post-diversion central portion, we have (0.00044/1.17) = 0.000376, or 0.0004, when rounded off.

The natural channel slope of Reach D plots with the data points for other tortuous channels (Figure 2.4). The valley slope plots above the Ackers-Charlton line which divides straight from meandering streams (Figure 2.3). The absence of scroll bars (Figure 4.23), the small width to depth ratios (Table 4.13), the steep slopes of the inside banks of bends, and the frequent cutoffs which characterise Reach D are also often found on these other low slope - suspended load streams with tortuous channel patterns.

Although the natural planform in Reach D is similar to that in the downstream portion of Reach C, their channel perimeters are not composed of the same type of sediments (compare Figure 4.14 to Figure 4.24). Reach D has a sandy bed and silty sand banks. Reach C has a channel perimeter of silty clay. However, both reaches have valley walls composed of Glacial Lake Edmonton silts and clays. It may be that large amounts of silts and clays are introduced into the

TABLE 4.12. Distance downstream from Big Lake in km regressed on channel perimeter sediment variables and cross-section variables for Reach D.

Ref. No.	Regressor	Exponent	Student's t of exponent	Two-tailed significance of t (%)	Coefficient of determination, r^2	Sample size
1	Percent of silt and clay in the channel banks, %SCBK	0.008	1.33	50	0.11	16
2	Percent of silt and clay in the channel bed, %SCBD	0.001	0.34	<50	0.008	16
3	Mean bank sediment size, MBK	-0.01	-1.96	90	0.22	16
4	Mean bed sediment size, MBD	-0.004	-1.16	50	0.09	16
5	Observed width to max. depth ratio, $(W/Dx)_o$	-0.02	-0.47	<50	0.07	5
6	Observed width to mean depth ratio, $(W/Dm)_o$	-0.01	-0.38	<50	0.04	5
7	Observed width, W_o	0.02	0.26	<50	0.02	5
8	Max. depth at observed water level, $(Dx)_o$	0.04	0.91	50	0.22	5
9	Mean depth at observed water level, $(Dm)_o$	0.02	0.68	<50	0.13	5
10	Observed area, A_o	0.06	1.26	50	0.34	5
11	First-break-in-slope width to maximum depth ratio, $(W/Dx)_{fb}$	-0.02	-0.49	<50	0.07	5
12	First-break-in-slope width to mean depth ratio, $(W/Dm)_{fb}$	-0.03	-1.01	50	0.25	5
13	First-break-in-slope width, W_{fb}	-0.05	-2.72	90	0.71	5
14	Max. depth at first-break-in-slope water level, $(Dx)_{fb}$	-0.08	-3.14	90	0.77	5
15	Mean depth at first-break-in-slope water level, $(Dm)_{fb}$	-0.04	-0.61	<50	0.11	5
16	First-break-in-slope area, A_{fb}	-0.06	-20.84	99.8	0.99	5

Figure 4.23 Channel cross-sections along Reach D of the Sturgeon River. Cross-section locations are given on Figure 4.21.

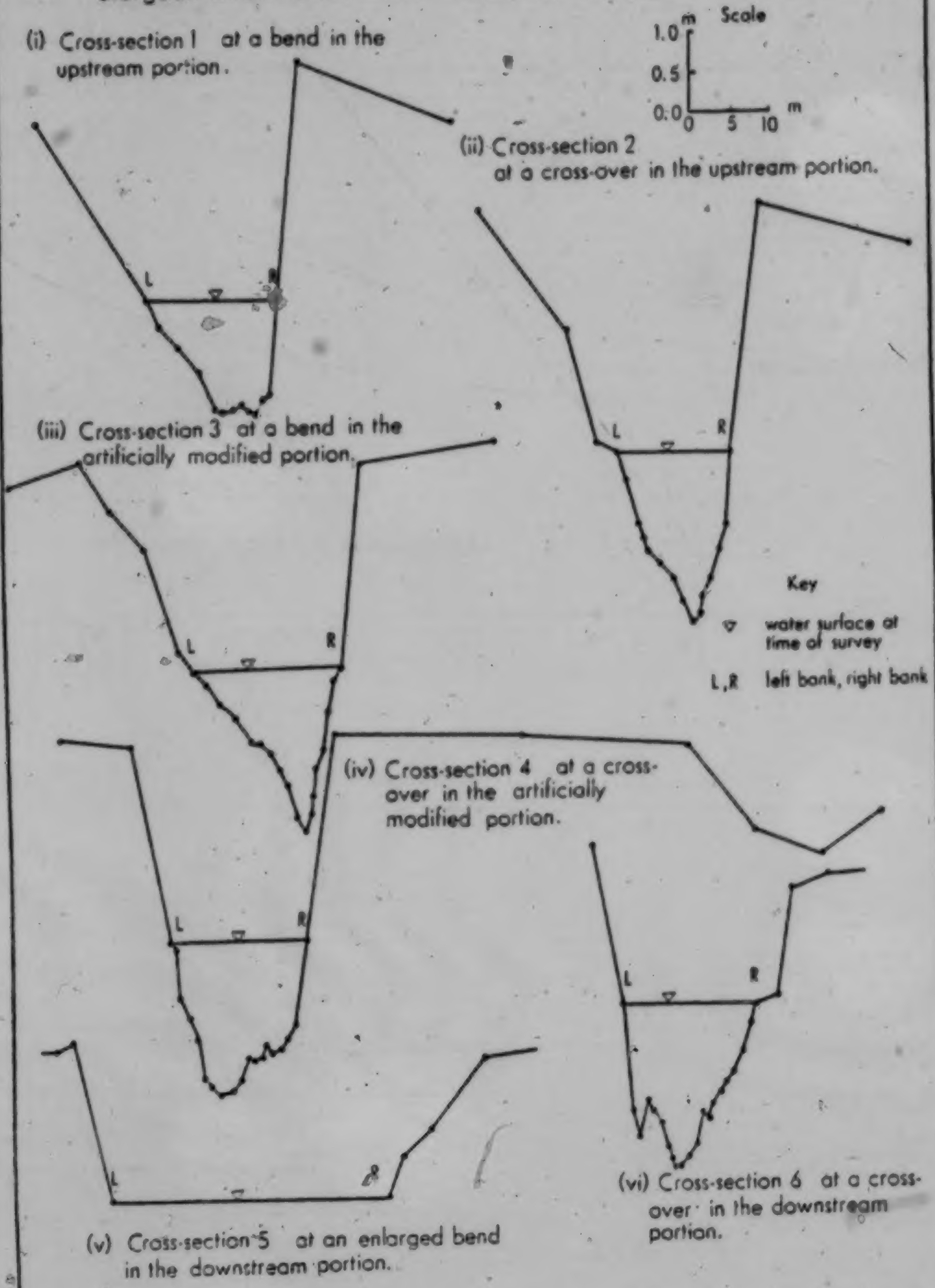

(i) Cross-section 1 at a bend in the upstream portion.
(ii) Cross-section 2 at a cross-over in the upstream portion.
(iii) Cross-section 3 at a bend in the artificially modified portion.
(iv) Cross-section 4 at a cross-over in the artificially modified portion.
(v) Cross-section 5 at an enlarged bend in the downstream portion.
(vi) Cross-section 6 at a cross-over in the downstream portion.
Scale
m
1.0
0.5
0.0
0
5
10
m
L
R
▽
Key
▽ water surface at time of survey
L, R left bank, right bank

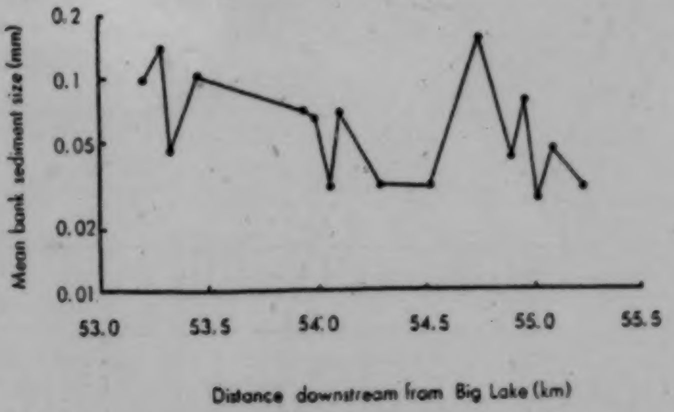
TABLE 4.13. The observed width to maximum depth ratio, (W/Dx)o, and the first-break-in-slope width to maximum depth ratio, (W/Dx)fb, for Reach D.

Distance downstream from Big Lake (km)	(W/Dx)o	(W/Dx)fb
53.38	12.4	8.5
53.46	6.6	6.7
54.11	8.6	7.4
54.19	8.5	5.7
55.15	11*	8*
55.18	8.0	7.1

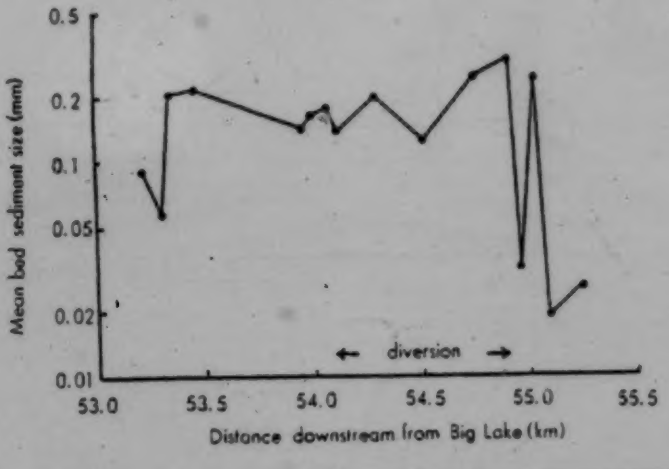
* These values are only approximate. All that is known is that the maximum observed depth is greater than 2.8 m. It was assumed for these calculations to be 3 m.

Figure 4.24 Sediment size characteristics from the channel perimeter of Reach D.

(a) Mean sediment sizes of the bank samples vs distance downstream for Reach D. Left and right bank sediment samples are averaged.



(b) Mean sediment sizes of the bed samples vs distance downstream for Reach D.



channel's sediment load when undercutting of the valley walls causes calving of the sediments into the river. This large proportion of suspended load may contribute to the formation of the tortuous channel pattern. The valley bottom is covered by trees in the contorted portion of Reach C, which may obscure some meander scars. However, it does appear as if the valley bottom of Reach D has more scars than the valley bottom of Reach C. Thus, the channel in sandy sediments may be more active, although the planforms are similar (compare Figures 4.17 and 4.22a).

Most of the sediment variables do not have statistically significant downstream trends in Reach D (4.12-1 to 4.12-4) and the exponents are very small. There is a difference between the bed sediments of the natural portions and those of the artificially straightened portion (Figure 4.24). All the bed sediment samples in the central portion are well-sorted fine sand. The natural portions have an overall mean size of fine sand, but for individual samples, the mean sediment sizes range from silt to medium sand. The data also suggest that the pools in the downstream portion have finer sediments than the cross-overs. There is little variation from pool to cross-over in the central portion.

The smaller proportion of fine sediments in the central portion may be due, in part, to the lower input of Glacial Lake Edmonton silts and clays. Before the diversion, the river undercut the valley walls in four places along Reach

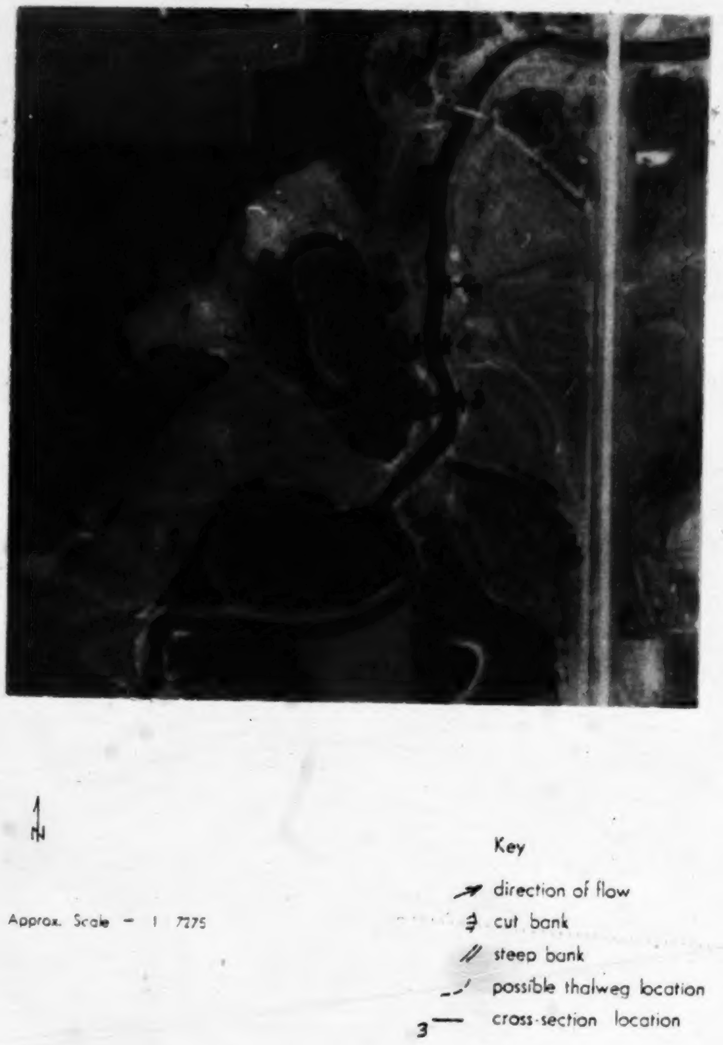
D. Now the river undercuts the valley walls at only one location. Also, the greater energy expenditure caused by the steeper channel slope of the central portion should permit the removal of finer sediments from the channel bed. The fine sediments may then be trapped in the pools in the downstream portion. The bed sediments in the two cross-sections immediately upstream of the central portion are similar to those in the straightened portion. Presumably headward erosion has steepened the channel slope just upstream of the diversion to produce this result (Yearke, 1971).

The channel slope of the diverted portion plots close to Lane's relationship which describes meandering streams. Thus, the channel in the central portion may attempt to reform a meandering pattern in this portion, although perhaps not a tortuous planform. If the input of silt and clay into the channel is necessary to produce the tortuous planform, say for the stabilisation of the channel banks, then the reduction of silt and clay in the central portion may mean that the new stable channel will be sinuous but not contorted.

The only information pertaining to the artificially created channel cross-sectional forms of the straightened portion is for the design cross-sectional form at the highway bridge (see Figure 4.21). Here the channel was to have a bottom width of 15.2 m and bank slopes of 0.5. Whether this was the form used for the artificial cutoffs is unknown. As of 1979, for cross-section 3, the inside bank had a slope of about 0.2 to 0.3, and the outside bank about 0.4 below the observed water level, and 0.8 above the observed water level. The bank slopes at cross-section 4 are slightly steeper (0.6) than the artificial values. Below water level, cross-section 3 is V-shaped and skewed towards the right bank. Cross-section 4 is somewhat skewed towards the left bank. From cross-section 3 the thalweg appears to move from the right bank to the left bank at the location of cross-section 4, and then to the right bank at location 4a, where a cut bank has formed (Figure 4.25). Air photographs of this portion show that a small bend at cross-section 4 has formed since 1962-63 (Figure 4.22). This indicates that the channel may be attempting to reform a meandering pattern in the central portion.

The width to depth ratios do not change markedly from the artificially straightened portion to the natural portion (Table 4.13). The observed cross-sectional form of the channel appears to have readjusted to a form close to the natural cross-sectional shape. As the bed sediments become finer, the observed width to depth ratios, (W/Dx)o and (W/Dm)o, decreases (A-91, A-92, A-97, A-98, A-87, A-88) as one would expect from the literature (Schumm, 1961). The regression analysis does not include cross-section 5 because it is an enlarged bend. The fact that the straightened portion does not have any of these enlarged bends may be significant for the channel in terms of the water surface

Figure 4.25 The central portion of Reach D, where a meandering pattern seems to be reforming after artificial straightening. The photograph is from 1977, 15 years after the diversion.



slope at lower discharges and in terms of the large variations in sedimentation environments between the enlarged bends and their adjacent cross-overs.

In conclusion, the natural contorted pattern of this reach is typical of other low slope channels in fine sediments. For Reach D, the fine sediments are provided by the Glacial Lake Edmonton deposits. The straightened portion has a smaller proportion of fine sediment in the bed sediments. This is probably due to the reduced input of Glacial Lake Edmonton fine deposits and to the greater ability of the water to erode and transport fine sediments because of the higher diversion channel slope. The straightened portion appears to be reforming a meandering planform.

4.7 Reach E

The upstream portion of Reach E has a contorted pattern (Figure 4.26), similar to the natural pattern of Reach D and the contorted portion of Reach C. The pattern in the central portion is variable. In the downstream portion, the channel is nearly straight. From the upstream to the downstream portion, sinuosity decreases from 1.74 to 1.01; mean meander wavelength increases from 132m to 258m, and mean radius of curvature increases from 46m to 110m.

The valley form in this reach appears to exert some control on the planform. The valley bottom width (Table 4.14

Figure 4.26 The Sturgeon River along Reach E.

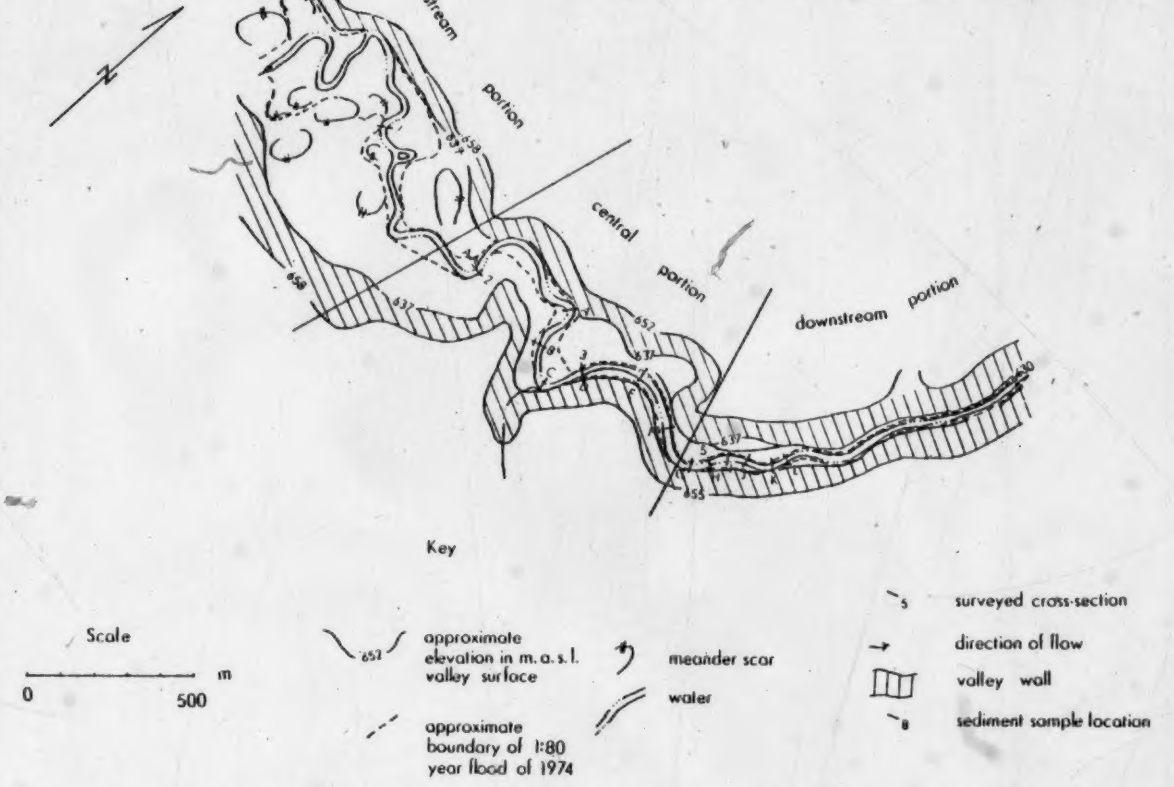


TABLE 4.14. Valley bottom widths along Reach E.

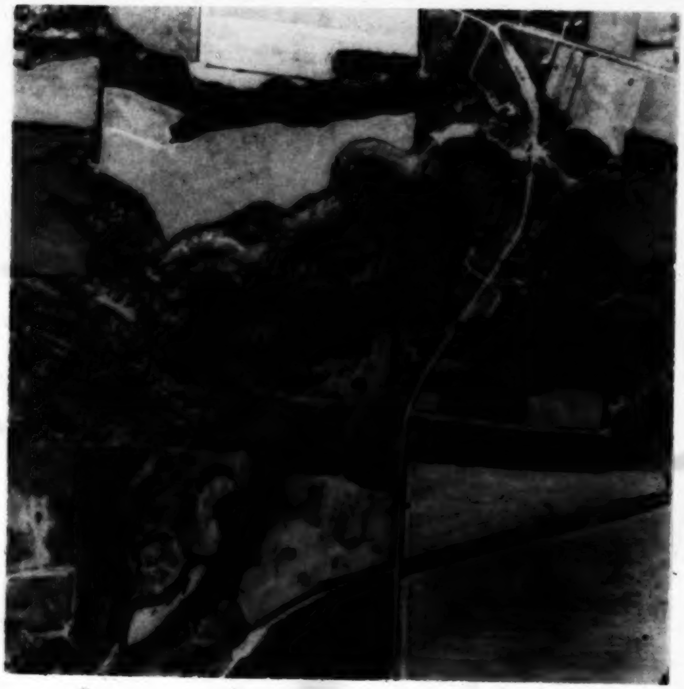
Portion	Distance Downstream (km)	Valley Bottom Widths (m)
Upstream	62.3	360
	62.5	456
	62.5	540
	62.8	564
	62.9	540
	63.3	492
	63.3	480
	63.4	468
	63.4	456
Central	63.6	384
	63.8	264
	63.9	144
	64.1	132
	64.1	180
	64.2	240
Downstream	64.7	144
	65.0	84
	65.2	60
	65.4	72
	65.5	60
	65.7	48
	65.7	36

decreases significantly with distance downstream (t=-12.189). The small valley bottom width and small meander amplitudes of the downstream portion both suggest that channel erosion has been primarily vertical with only a small lateral component. The wider valley bottom and the frequent occurrence of meander scars (Figure 4.27) in the upstream portion indicate greater lateral movement there.

The river is occasionally confined by the valley walls in the upstream and central portions, and frequently confined in the downstream portion. In the upstream portion, these walls are composed of Glacial Lake Edmonton silts and clays. In the central and downstream portions, the walls are composed of bedrock capped by sands and gravels. The difference in valley form may be due to greater resistance of the valley walls to erosion in the downstream portion.

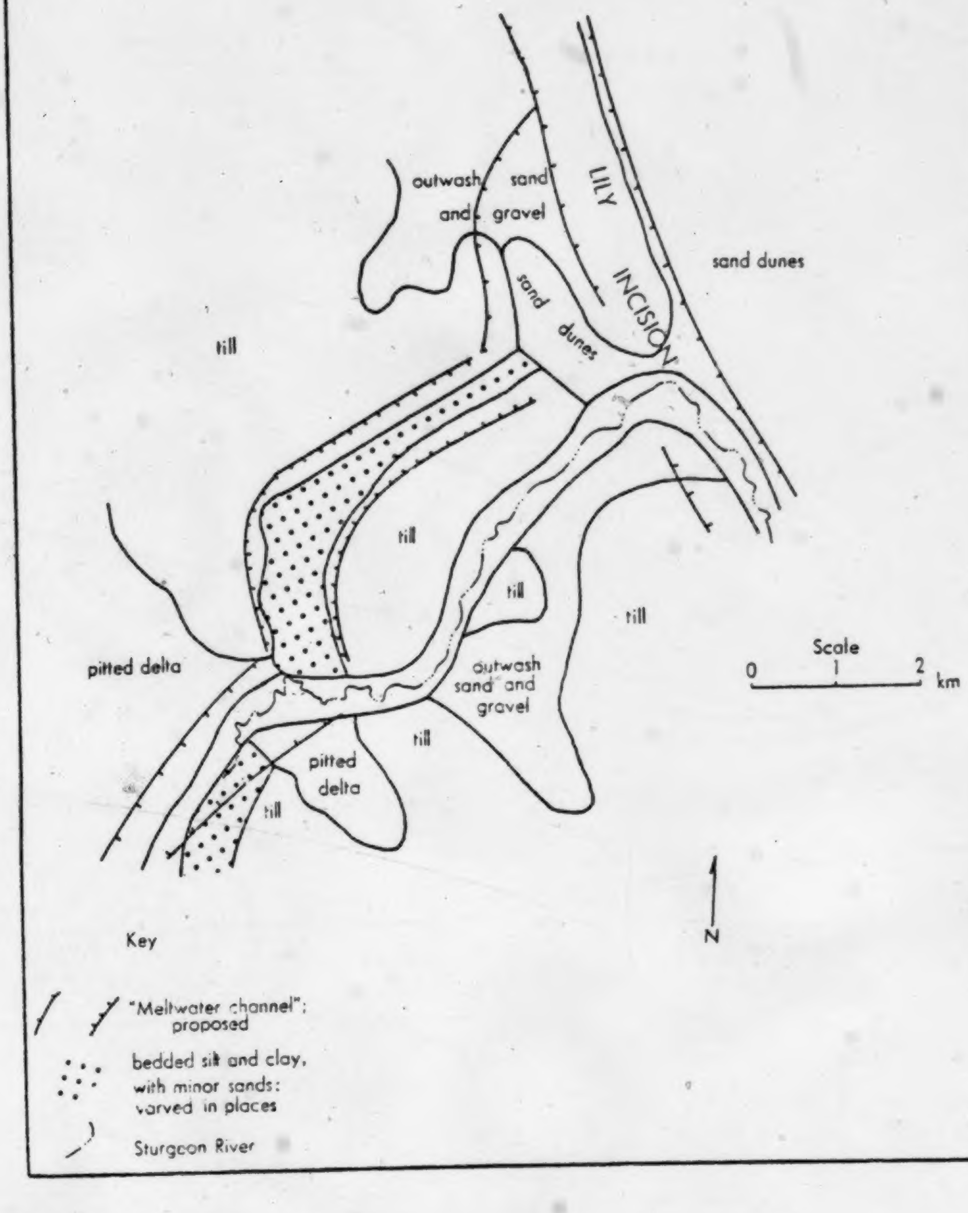
It may also be that the valley in the upstream portion existed before the present Sturgeon River whereas the valley in the downstream portion is relatively young. It seems possible that the silt-clay deposit between the Sturgeon Valley and the Lily Incision (Figure 4.28) may represent a continuation of the meltwater channel proposed by Bayrock (1972) for the river upstream of Reach E. The meltwater channel and the valley with the silt-clay deposits have similar valley top widths and both valleys are infilled with Glacial Lake Edmonton sediments. Bayrock's "meltwater channel" ends where the proposed "meltwater channel" begins and then begins again where the proposed "meltwater channel"

Figure 4.27 Meander scars in the upstream portion of Reach E



Approx. Scale – 3.2cm to 500 m

Figure 4.28 Surficial geology in the Reach E region (from Bayrock, 1972) and the proposed 'meltwater channel' location.



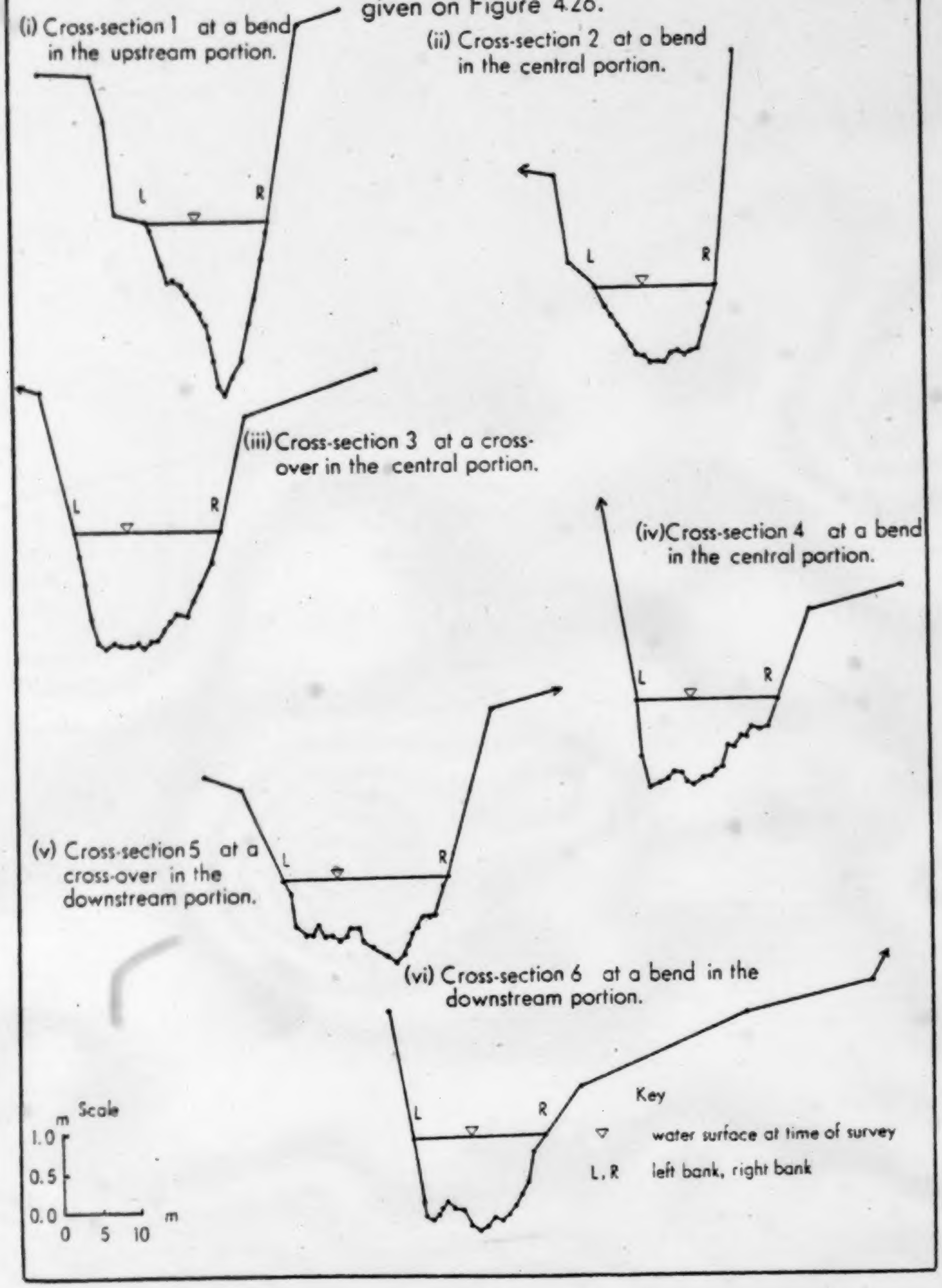
ends. Thus, it may be that the meltwater channel which excavated the valley along the upstream portion of Reach E, also excavated this other valley. The whole valley was later infilled with Glacial Lake Edmonton sediments and then a portion of the valley was reexcavated by the Sturgeon River. However, the Sturgeon River followed a new path downstream of the reexcavated portion. In the downstream portion of Reach E, the valley appears to be geologically young, and lateral erosion has not been great enough to remove the confining effect of the bentonitic shale and sandstone which form the valley walls.

There is only one measured cross-section in the upstream portion, and this was taken near the central portion. There are no first-break-in-slope data for cross-section 1. In the central portion, the cross-sections were taken too close together to have separate planform data. Thus, the cross-sectional data set is very small for this reach, and, in fact, it is too small for statistical analysis. The limited observed cross-sectional data do not show any strong downstream trends (Table 4.3, Figure 4.29).

The channel and valley slope data are poor. The channel slope for the stretch which includes the upstream portion of Reach E is 0.0006 and the valley slope is 0.0011. For the stretch including the central and downstream portions, the channel slope is 0.002 and the valley slope is 0.0022.

In the upstream portion, features such as narrow and deep cross-sections, the steep inside banks of bends, point

Figure 4.29 Channel cross-sections along Reach E of the Sturgeon River. Cross-section locations are given on Figure 4.26.



(i) Cross-section 1 at a bend in the upstream portion.

(ii) Cross-section 2 at a bend in the central portion.

(iii) Cross-section 3 at a cross-over in the central portion.

(iv) Cross-section 4 at a bend in the central portion.

(v) Cross-section 5 at a cross-over in the downstream portion.

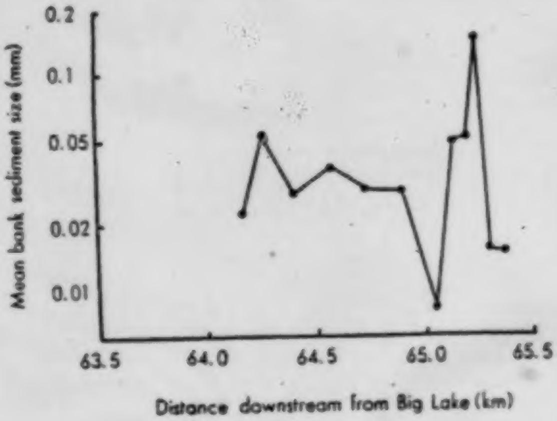
(vi) Cross-section 6 at a bend in the downstream portion.

benches (Figure 4.29), and cutoffs (Figure 4.27) are characteristic of the other Sturgeon River reaches which have tortuous channel patterns. The relatively steep slope of the upstream portion of Reach E compared with that of the natural pattern of Reach D and of the downstream portion of Reach C may be the result of measuring the slope from a topographic map: the slope value includes part of the gravel-bedded channel upstream beyond Reach E, as well as part of the central portion of Reach E.

In the central and downstream portions, the bank sediments are variable and the bed sediments are predominantly gravel (Figure 4.30). There are no statistically significant downstream changes in sediment size along these two portions (4.15-1, 4.15-2). No sediment samples were taken from the upstream portion but limited field observations indicate that the beds are predominantly sand with small amounts of gravel and the banks are composed of silty sand. Because of the poor quality of the sediment data, no meaningful statistical relations between planform characteristics and sediments can be drawn. However, the data suggest that the upstream portion has sediments which are similar to those of Reach D, i.e. a sandy bed with an input of Glacial Lake Edmonton sediments from the valley walls. In the central and downstream portions, the channel slope becomes steeper and the bed sediments much coarser. This agrees with observations in the literature which show that an increase in sediment size is often associated with

Figure 4.30 Sediment size characteristics from the channel perimeter of Reach E.

(a) Mean sediment-sizes of the bank samples vs distance downstream for Reach E.
* Left and right bank samples are averaged.



(b) Mean sediment sizes of the bed samples vs distance downstream for Reach E.

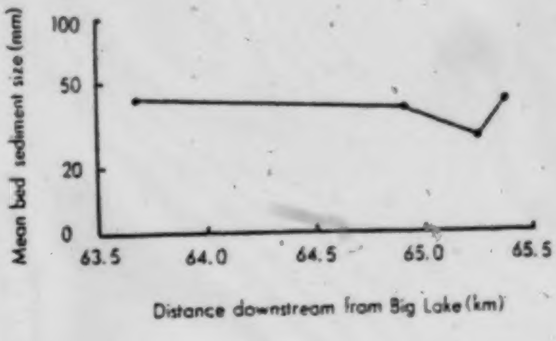


TABLE 4.15. Distance downstream from Big Lake (km) regressed on channel perimeter sediment variables and cross-section variables for Reach E.

Ref. No.	Data set	Regressor	Exponent	Student's t of exponent	Two-tailed significance of t (%)	Coefficient of determination, r^2	Sample size
1	Reach E	Percent of silt and clay in the channel banks, %SCBK	-0.004	-0.52	<50	0.03	12
2		Mean bank sediment size, MBK	-0.0004	-0.13	<50	0.002	12
3		Observed width to max. depth ratio, (W/Dx)o	0.03	2.08	80	0.52	6
4		Observed width to mean depth ratio, (W/Dm)o	0.03	1.14	50	0.25	6
5		Observed width, Wo	0.05	0.70	<50	0.11	6
6		Maximum depth at observed water level, (Dx)o	-0.03	-1.60	80	0.39	6
7		Mean depth at observed water level, (Dm)o	-0.02	-0.85	50	0.15	6
8		Observed area, Ao	-0.004	-0.12	<50	0.003	6
9		First-break-in-slope width to max. depth ratio, (W/Dx)fb	0.04	2.81	90	0.73	5
10		First-break-in-slope width to mean depth ratio, (W/Dm)fb	0.03	2.18	80	0.61	5
11		First-break-in-slope width, Wfb	0.04	1.08	50	0.28	5
12		Max. depth at first-break-in-slope water level, (Dx)fb	-0.03	-1.07	50	0.28	5
13		Mean depth at first-break-in-slope water level, (Dm)fb	-0.02	-0.99	50	0.25	5
14		First-break-in-slope area, Afb	-0.005	-0.30	<50	0.03	5

an increase in channel slope (see Section 2.6).

Only part of the valley flat was flooded by the 1974 1 in 80 year flood, and the area flooded decreases downstream along the reach (Figure 4.26). In the downstream portion of Reach E, the discharge was near bankfull during the 1974 flood. Because the bankfull discharge has such a large return period, the downstream portion is considered to be entrenched and the dominant discharge to be the mean annual flood, 24.1 cumecs (Neill *et al.*, 1970), as recommended for entrenched channels (Ackers, 1980).

The channel slope-discharge data point of the central and downstream portions plots near the Leopold-Wolman relationship which separates meandering from braiding channels on the slope-discharge diagram (Figure 2.2). If the downstream portion is near the transition to braiding, one may explain the lower sinuosity of this portion in terms of the slope-sinuosity relationship of Schumm and Khan (1972): after a certain slope is exceeded, the meandering tendency of the channel begins to decline and the channel straightens as it approaches the change to a braided pattern. Therefore, as the slope becomes steeper along Reach E, the channel straightens.

In summary, the upstream portion's channel pattern is probably controlled by a low channel slope and fine sediment load producing a contorted planform. The downstream portion is confined by the bedrock valley walls which restrict lateral erosion, resulting in small, low amplitude meanders.

The very limited data lead one to speculate that the valley of the central and downstream portions were excavated entirely postglacially, after the disappearance of Glacial Lake Edmonton. The gravel bed sediments require a steep slope for erosion and transport. To create this steep slope, the river follows an almost straight channel pattern, and so the amount of lateral erosion by the river is small. Thus, the valley remains narrow and the channel confined and nearly straight. However, the data for this reach are of very poor quality. There are so few bed samples that the relationships between the bed sediment variables and planform cannot be properly investigated. The cross-sectional data do not cover the reach adequately and the slope data are not accurate.

4.8 Reach F

The upstream portion of Reach F has a low sinuosity of 1.22. The downstream portion, with a sinuosity of 1.92, has a compound pattern (Figure 4.31). In 1966-67, the central portion was artificially straightened (Alberta Department of Highways, 1966). This removed two meander bends from the central portion of the reach. A natural cutoff formed gradually between 1924 and 1976 in the central portion, downstream from the diversion (Figure 4.32). Thus, the central portion, with a sinuosity of 1.01, is now almost straight.

Figure 4.31 The Sturgeon River along Reach F.

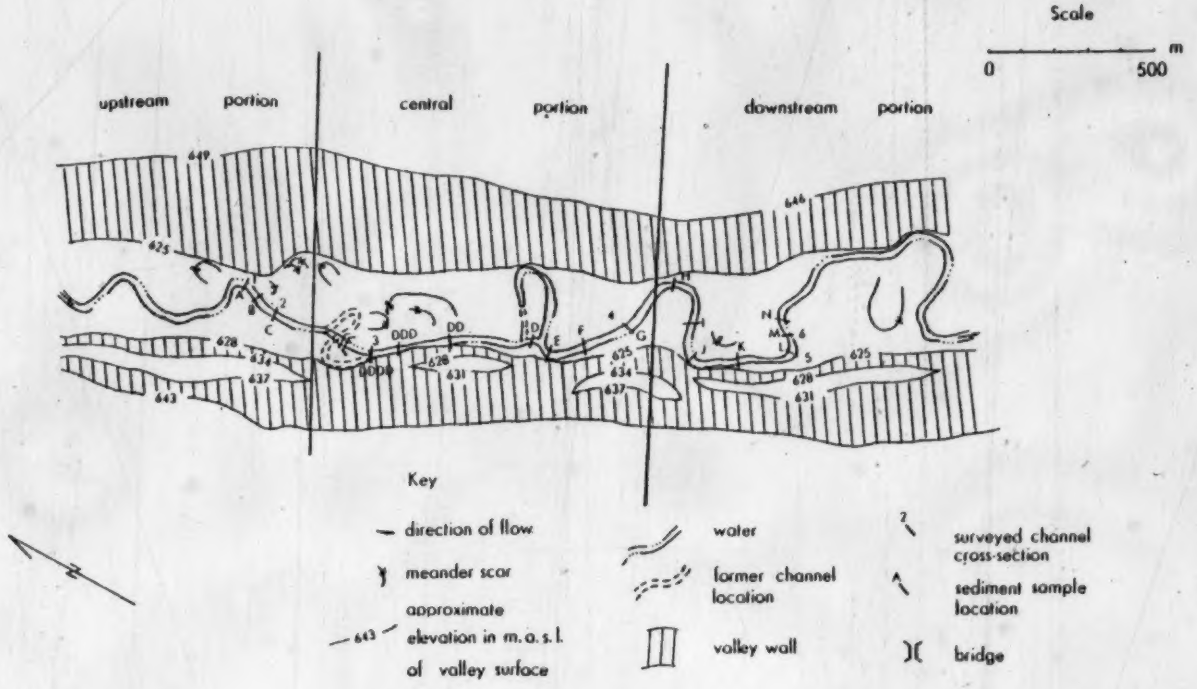
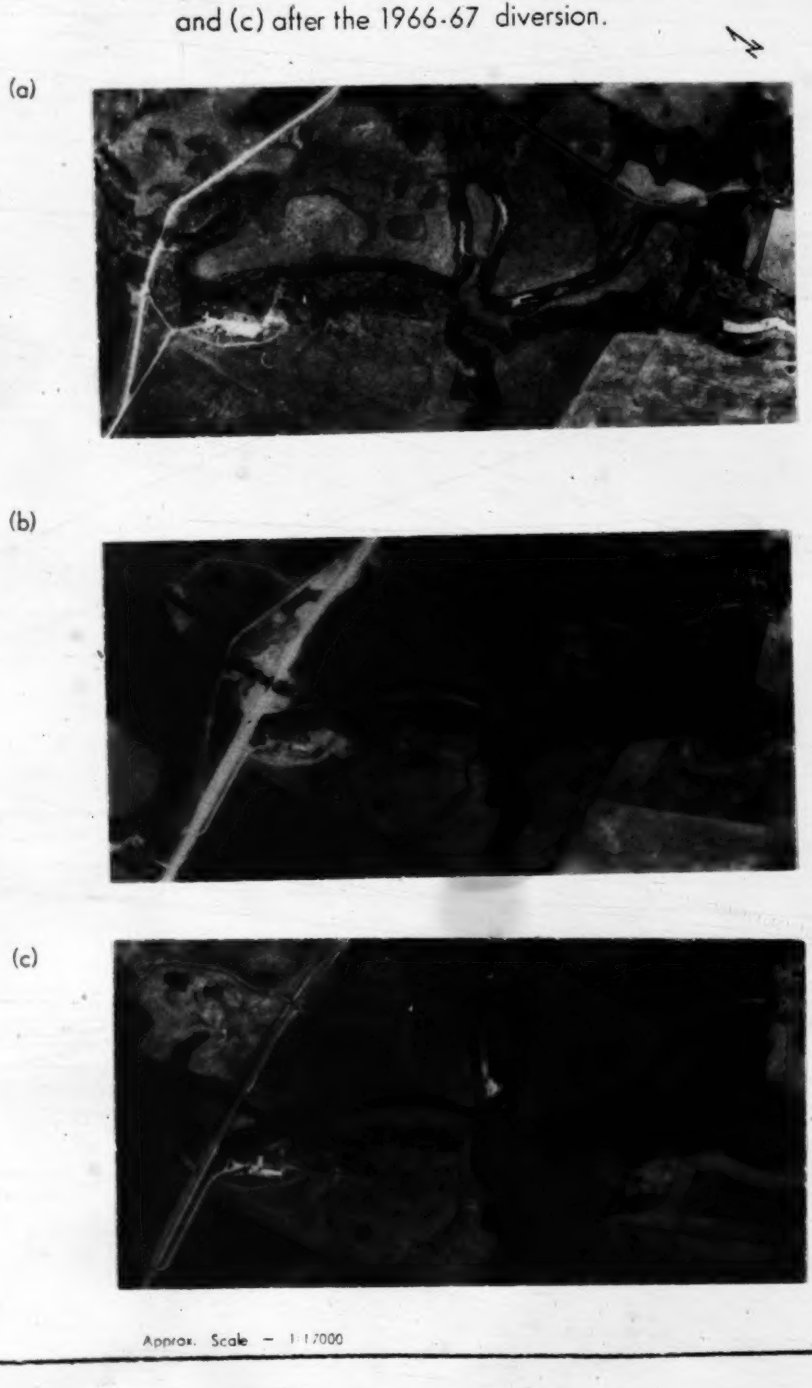


Figure 4.32 Reach F (a) before; (b) during; and (c) after the 1966-67 diversion.



Approx. Scale – 1:17000

The average wavelength of the simple meanders of the upstream portion is 230 m, similar to the average value for the small meanders, 200 m. The average wavelength for the large meanders is 420 m. There are no statistically significant downstream changes in planform for the simple or small meander data (4.6-16 to 4.6-18) except for amplitude, Amp, which has a very small exponent. The small meanders appear to be maintaining a spacing similar to that in the simple meanders. This supports Keller's (1972) and Lewin's (1972) hypothesis that small meanders are created within a large pattern so that the pool spacing is adjusted to the relatively small width. However, this does not explain why the large meanders are found in the downstream portion and not in the upstream portion.

Just upstream of Reach F, the Sturgeon Valley makes an abrupt change in direction from roughly a SW-NE to a NW-SE orientation (Figure 4.33). The portion of the valley following the NW-SE orientation, including Reach F, is called the Lily Incision (Bibby, 1974b). Bayrock (1972) indicated that the Lily Incision was formed by a meltwater channel. The width of the Lily Incision valley top is approximately constant along most of the incision, but the depth of the incision is greater where the incision is occupied by the Sturgeon River (Table 4.16). This suggests that the Sturgeon River has downcut the Lily Incision since the initial excavation of the whole incision, but that lateral erosion by the Sturgeon River has been confined to

Figure 4.33 The Lily Incision, from (Bayrock, 1972).

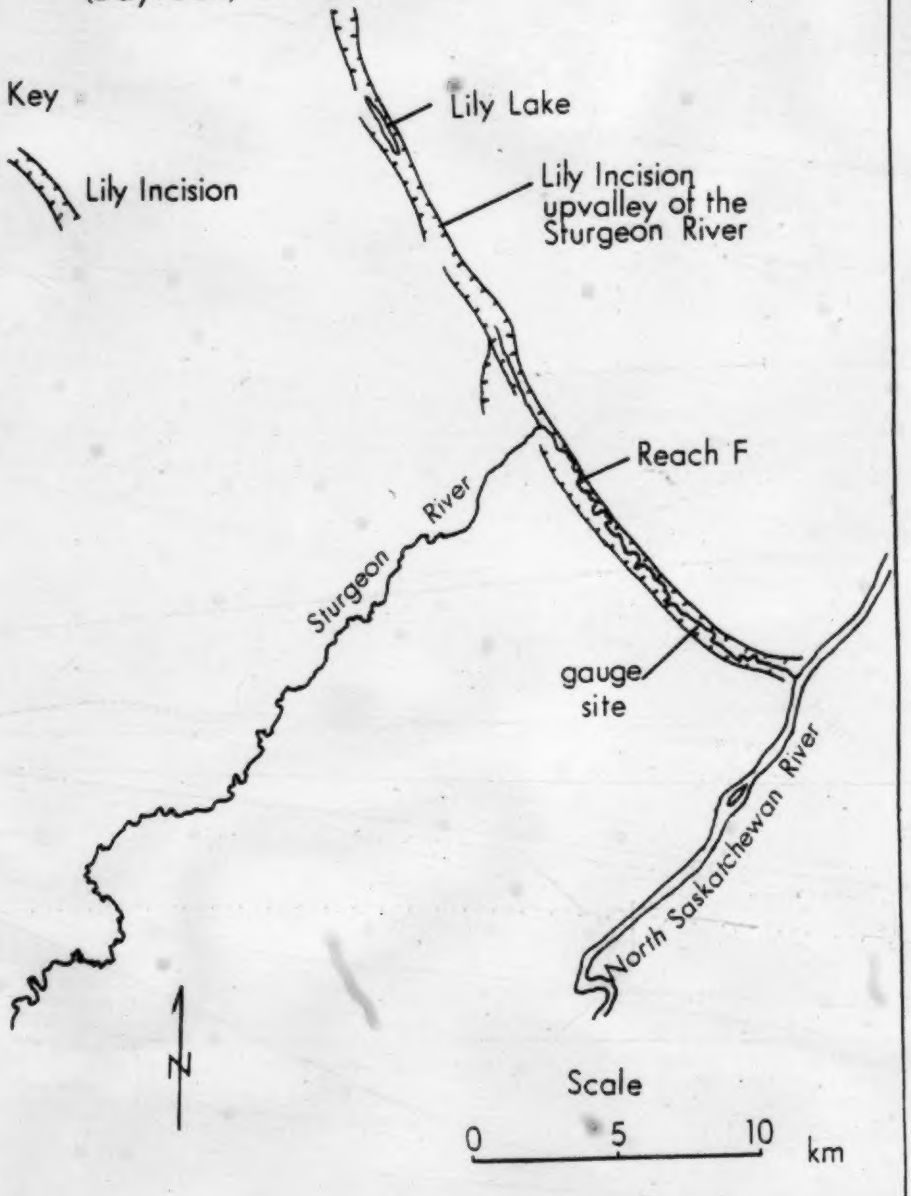


TABLE 4.16. Valley top widths and depths of incision along the Lily Incision. The reach locations are shown on Figure 4.33.

Reach	Valley Top Widths (m)	Average Valley Top Width (m)	Depth of Valley Incision (m)
Lily Incision upvalley of the Sturgeon River	600	642	approx. 15
	600		
	700		
	500		
	700		
	750		
Reach F	616	720	26
	762		
	853		
	738		
	671		
	634		
	671		
	768		
	771		
	716		
Gauge site	671	601	26
	610		
	625		
	588		
	579		
	533		
	600		

the valley cut by the meltwater channel.

The valley bottom width and the meander belt width both increase downstream along Reach F, but the proportion of the valley bottom occupied by the meander belt increases downstream (Table 4.17). In places in the downstream portion, the channel is confined by the valley walls but the channel in the upstream portion is not confined by the valley walls. From this it appears that the downstream development of large meanders is not due to an increase in valley width.

It has been found that meander wavelength increases as the sediment becomes coarser for a given discharge (Schumm, 1967; Ackers, 1980). There is no significant downstream change in either bed or bank sediment size (4.18-1, 4.18-2 and Figure 4.34). Very few bed samples were taken and so the regression relations are not reliable. It would have been better to have data which in some way reflected what proportion of the bank is composed of predominantly gravel and what proportion is predominantly sand and silt. As it is, these statistical relations are probably not geomorphically meaningful.

The observed, first-break-in-slope, and valley-flat break-in-slope channel cross-sectional characteristics do not show any significant downstream trends (4.18-3 to 4.18-20 and Figure 4.35). The valley-flat break-in-slope cross-sections are larger than the first-break-in-slope channel cross-sections for this reach and the

TABLE 4.17. Meander belt widths and valley bottom widths for Reach F.

Distance Downstream from Big Lake (km)	Meander Belt Width (m)	Valley Bottom Width (m)
72.69	122	268
73.10	146	229
73.42	192	207
74.06	244	280
74.38	274	305
74.63	259	204
75.27	283	335
75.83	305	381
76.07	357	396
76.80	320	320

TABLE 4.18. Distance downstream from Big Lake in km regressed on channel perimeter sediment variables and cross-section variables for Reach F.

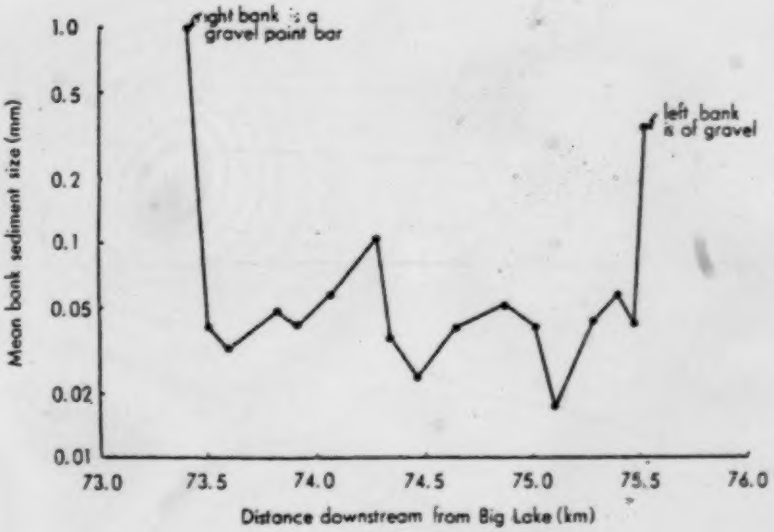
Ref. No.	Data set	Regressor	Exponent	Student's t of exponent	Two-tailed significance of t (%)	Coefficient of determination, r^2	Sample size
1	Reach F	Percent of silt and clay in the channel banks, %SCBK	0.006	1.10	50	0.07	17
2		Mean bank sediment size, MBK	-0.001	-0.58	< 50	0.02	17
3		Observed width to maximum depth ratio, (W/Dx)o	-0.004	-0.23	< 50	0.01	6
4		Observed width to mean depth ratio, (W/Dm)o	0.0003	0.02	< 50	0.00007	6
5		Observed width, Wo	-0.02	-0.34	< 50	0.03	6
6		Maximum depth at observed water level, (Dx)o	0.003	0.14	< 50	0.005	6
7		Mean depth at observed water level, (Dm)o	-0.003	-0.15	< 50	0.005	6
8		Observed area, Ao	-0.008	-0.30	< 50	0.02	6
9		First-break-in-slope width to max. depth ratio, (W/Dx)fb	-0.01	-0.26	<50	0.02	6
10		First-break-in-slope width to mean depth ratio, (W/Dm)fb	-0.03	-0.78	50	0.13	6
11		First-break-in-slope width, Wfb	-0.009	-0.18	< 50	0.008	6
12		Max. depth at the first-break-in-slope water level, (Dx)fb	0.006	0.13	< 50	0.004	6
13		Mean depth at the first-break-in-slope water level, (Dm)fb	0.04	0.93	50	0.18	6
14		First-break-in-slope area, Afb	0.02	0.46	<50	0.05	6

TABLE 4.18, continued:

Ref. No.	Data set	Regressor	Exponent	Student's t of exponent	Two-tailed significance of t (%)	Coefficient of determination, r^2	Sample size
15	Reach F	Valley-flat break-in-slope width to max. depth, (W/Dx)vf	0.02	0.58	<50	0.08	6
16		Valley-flat break-in-slope width to mean depth, (W/Dm)vf	-0.03	-1.20	50	0.27	6
17		Valley-flat break-in-slope width, Wvf	0.02	1.16	50	0.25	6
18		Max. depth at valley-flat break-in-slope water level, (Dx)vf	0.04	1.03	50	0.21	6
19		Mean depth at valley-flat break-in-slope water level, (Dm)vf	-0.90	-1.04	50	0.21	6
20		Valley-flat break-in-slope area, Avf	0.02	1.11	50	0.24	6

Figure 4.34 Sediment size characteristics from the channel perimeter of Reach F.

(a) Mean sediment sizes of the bank samples vs distance downstream for Reach F. Left and right bank samples are averaged.



(b) Mean sediment sizes of the gravel samples vs distance downstream for Reach F.

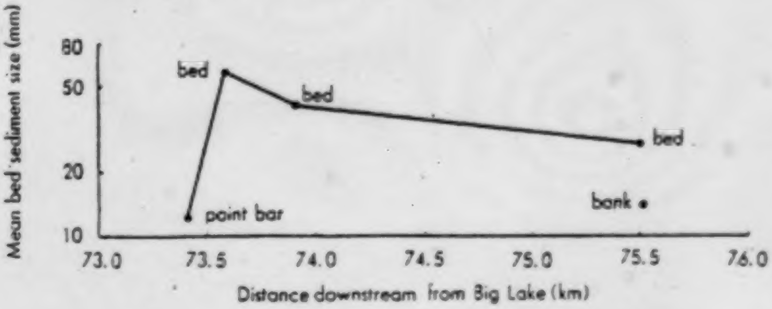
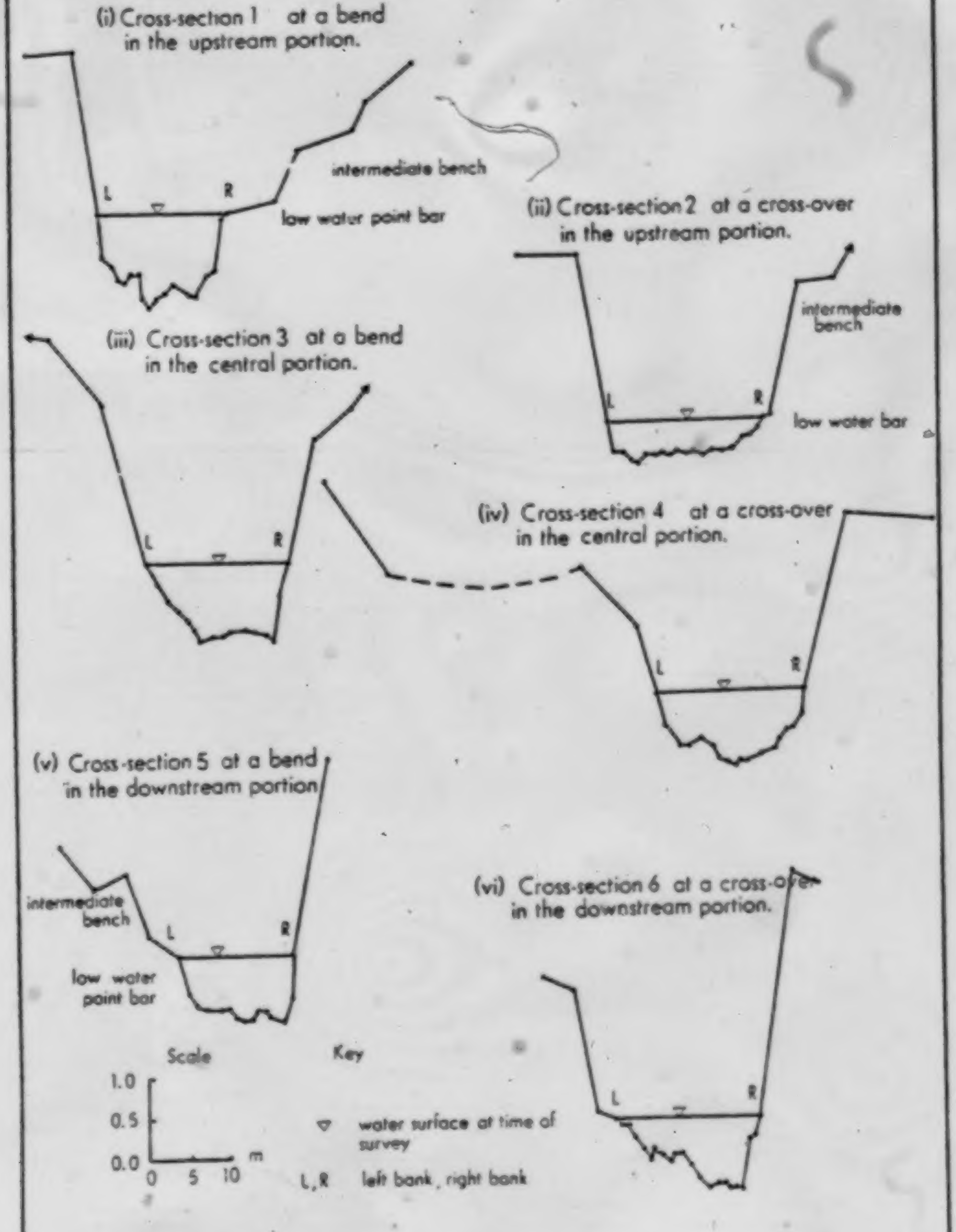


Figure 4.35 Channel cross-sections along Reach F. Cross-section locations are given on Figure 4.31.


(i) Cross-section 1 at a bend in the upstream portion.
intermediate bench
L
R
low water point bar
(ii) Cross-section 2 at a cross-over in the upstream portion.
intermediate bench
L
R
low water bar
(iii) Cross-section 3 at a bend in the central portion.
L
R
(iv) Cross-section 4 at a cross-over in the central portion.
L
R
(v) Cross-section 5 at a bend in the downstream portion
intermediate bench
L
R
low water point bar
(vi) Cross-section 6 at a cross-over in the downstream portion.
L
R
Scale
1.0
0.5
0.0
0
5
10
m
Key
▽ water surface at time of survey
L, R left bank, right bank

first-break-in-slope cross-sections are larger than the observed cross-sections (Table 4.3).

Unlike the small meanders of reaches A to C, the small meanders of Reach F are visible at higher flows. This indicates that these meanders might be related to some channel width larger than the observed channel width, Wo, say the first-break-in-slope channel width, Wfb. However, the simple and small meander wavelength data are not significantly related to Wfb (t=0.221, less than 50% sig.) but are significantly and positively related to Wo (t=1.650, 80% sig.). The simple or large meander wavelength data are not significantly related to either the first-break-in-slope channel width (t=0.368 and t=0.113, less than 50% sig.) or the valley-flat break-in-slope width (t=0.176, less than 50% sig.). However, the cross-sectional sample size is small and so does not provide reliable statistical results.

Channel migration along this reach is predominantly by avulsion rather than continuous lateral-migration as evidenced by the presence of cutoffs, the small point bars, and the absence of scroll bars. It seems that channel erosion has been predominantly vertical rather than lateral, resulting in channel entrenchment and small point bars.

Very little of the valley flat was flooded during the 1974 flood. Thus, this reach will be considered to be entrenched (see Section 3.2.3). Inchannel benches occur at some cross-sections (Figure 4.35) and may be related to some more frequent recurrence interval than is Surface I

(Woodyer, 1968).

The natural channel slope of the diverted portion was 0.000353 and the diversion slope is 0.00174, almost an order of magnitude steeper (Alberta Department of Highways, 1966). The valley slope is 0.00087. A possible reason for the downstream change in the natural meander pattern is a downstream change in valley slope according to Schumm and Khan's (1972) slope-sinuosity relation. However, the valley slope data are very poor and it is not known if the valley slope changes along the reach.

The slope-discharge data point for the pre-1966 channel plots in the meandering range of the Leopold-Wolman relation (Figure 2.2). The data point for the diversion is close to the line between meandering and braiding, but is still within the meandering range. Thus, the channel might attempt to reform a meandering pattern in this reach (Emerson, 1971; Keller, 1978).

The lag surface of fine gravels (Figure 4.34) on the point bar at cross-section 1 indicates that there is a relatively high shear stress on this point bar. This may mean that headward erosion is occurring upstream of the diversion, steepening the upper portion by straightening the planform. At cross-section 2 (Figure 4.35), the small bar along the right bank and the maximum channel depth along the left bank are perhaps the result of a new bend developing in the diverted portion as the channel attempts to reduce the slope of this portion.

Cross-section 3 is located at the downstream end of the diversion. Before the diversion, there was a riffle at this location (Alberta Department of Highways, 1966). As a result of the diversion there is now a bend at this location. Assuming that the planned work was the work done (Table 4.19), the following readjustments took place between 1966-67 and 1979:

(1) the inside bank slope has become gentler, especially below the observed water level;
(2) the outside bank slope has remained at approximately the design bank slope;
and (3) the channel bottom width and the channel top width have both become smaller.

From the comparison of the diversion cross-section and the 1979 cross-section, deposition has occurred at cross-section 3. This deposition has been predominantly along the inside bank where a gently sloping point bar has formed. There has also been erosion along the outside bank to form a cut bank. Thus, the channel form of the 1979 cross-section 3 is skewed, as are the cross-sections at natural bends along Reach F (Figure 4.35). However, the channel cross-sections were measured at slightly lower than mean discharge and the small bars at cross-sections 2 and 3 may be low flow features rather than readjustments to the diversion.

Deposition usually occurs downstream of a diversion (Yearke, 1971). However, in this reach, a cutoff formed downstream. The airphoto data indicate that this cutoff was forming before the artificial diversion. Consequently, any

TABLE 4.19. The form of cross-section 3 of Reach F immediately after the diversion (1966-67) (Alberta Department of Highways, 1966) and in July, 1979. It should be noted that the diversion plans were accompanied by the disclaimer: "The actual work done may or may not have been in accordance with these drawings."

Date of Cross-section	Bank Slope (Hor.:Vert.) Left Bank	Right Bank	Bottom Width of channel (m)	Top Width of Channel when depth is 1 m (m)
1966-67	2:1	2:1	19.8	23.8
1979	2.8:1* 6.8.1**	2.2:1* 2.2:1**	8.9	17.9

* Above water level, water discharge is 3 cumecs
** Below water level, water discharge is 3 cumecs

post-diversion deposition which might have taken place has not appreciably affected the formation of this cutoff.

In conclusion, the sediment, slope and cross-sectional data are too poor to determine the reason for the downstream change from simple to compound meanders. The amplitude of the large meanders of the compound pattern is sometimes limited by the width of the previously-cut Lily Incision but there do not seem to be any valley width constraints on the simple meanders. There is some evidence that the channel may be reforming a meandering pattern in the diverted portion, but it is not certain. It is not surprising that there is little evidence for the reformation of a meandering pattern after only thirteen years, especially if much of the erosion is downward rather than lateral.

4.9 General Comments and Conclusions

Summaries of the factors affecting each reach have been given at the end of each reach description. Some general comments about geomorphic processes along the Sturgeon River study reaches can be drawn from the above discussion. The pre-existing valley form is often important in determining the channel pattern by confining the channel and/or determining the valley slope within which the channel slope develops. Changes in planform are sometimes associated with a change in channel perimeter sediment type, although not always. It may be that sediment load rather than channel perimeter sediments should have been measured. The downstream changes in channel pattern are also often related to downstream changes in channel and valley slope. It seems that, at low channel slopes, small changes in slope are associated with very great changes in the channel pattern. Unfortunately, the slope data are imprecise for several of the study reaches. The downstream changes in channel form are not always associated with downstream changes in planform. This may be due to the small number of cross-sections measured as well as to the difficulties in determining an appropriate bankfull stage. Obviously, the study of the effects of the diversions of reaches D and F would have been better if the observations had been taken over a number of years. The small amount of of data on the prediversion and diversion characteristics of Reach D also hamper investigation of postdiversion changes.

5. ANALYSIS OF DATA

5.1 General Introduction

This chapter concerns the results of correlation and regression analyses primarily between the planform variables and the channel perimeter sediment variables, the channel cross-sectional variables, and the channel and valley slope variables. The regressions are log-linear and are referred to as "statistically significant" if the t statistics of the exponents are significant at 90% or a higher level. Correlation analysis has been used in addition to the regression analysis. First the simple regressions and correlations are discussed and then the multiple regressions and correlations. The regression relationships are given in tables in Appendix IV and the relations are referred to using the table letter and the reference number given in the table.

Only those relationships which are statistically significant are included in the text but Appendix IV lists both the statistically significant and insignificant relations. Summary diagrams are provided in the text showing the statistically significant results.

The relations have been calculated using data from individual reaches, from grouped data of similar reaches and from the data for all the reaches combined. Where there are compound meanders, there are separate relations for the large meanders and for the small meanders of the compound pattern. The "specific" planform data use the values of the bends for which channel cross-sections have been measured, whereas the "averaged" planform data use the mean of the planform values for a number of bends near to the measured cross-sections.

The cross-sectional measures have several values depending on the water level used. The "observed" cross-sectional values are those values obtained for the water level at the time of survey and are denoted by the letter "o". The "first-break-in-slope" cross-sectional data, labelled "fb", are produced by using the water level at the stage where the channel width begins to increase rapidly with small increases in channel depth (Section 3.2.3). This "first-break-in-slope" stage is used by some as a measure of the "bankfull" stage. Another method of measuring bankfull is to use the stage just before the river floods onto the valley flat, referred to here as the "valley-flat break-in-slope" stage and denoted by the letters "vf". The observed data are used in the analyses because they represent approximately the same discharge along a given reach, whereas the first-break-in-slope data represent a wide range of discharges along some reaches.

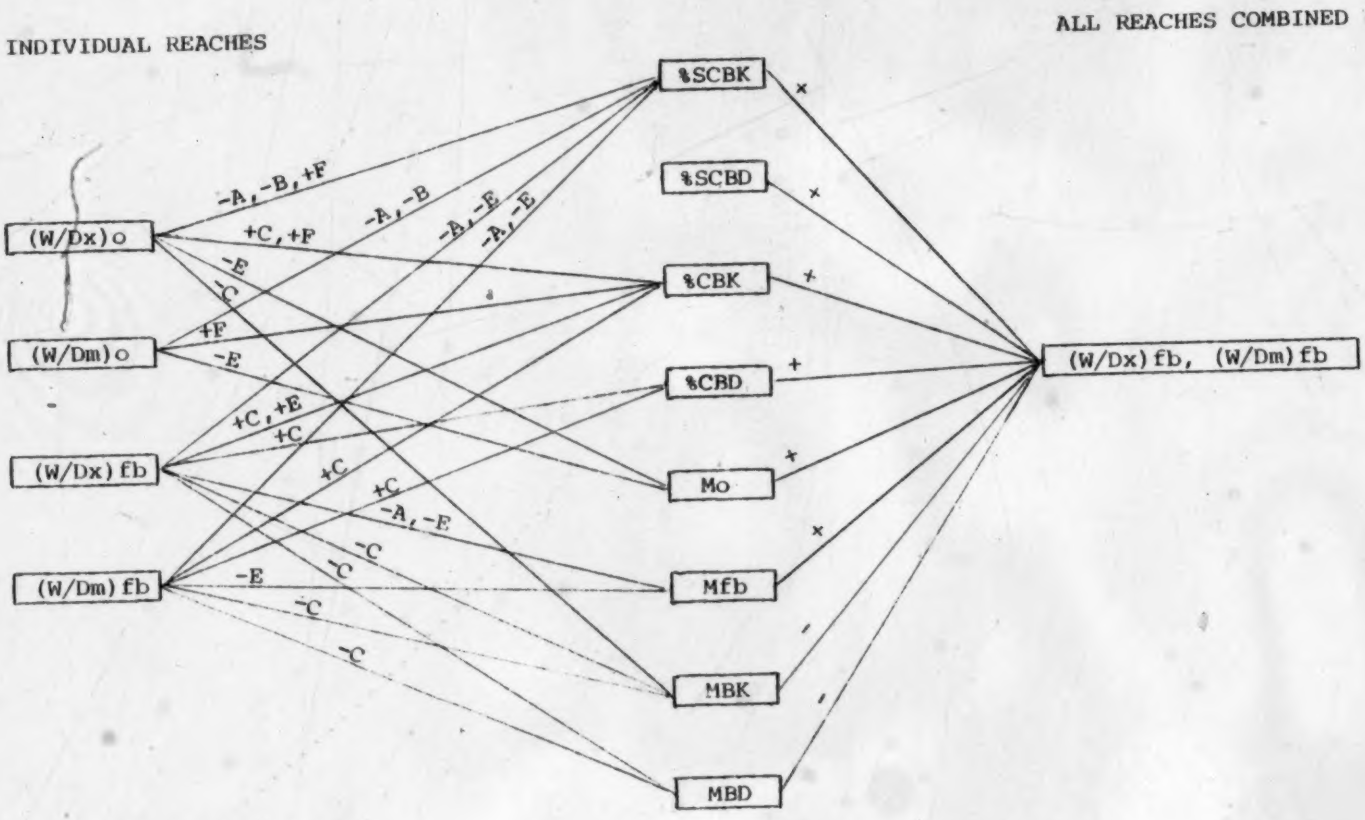
5.2 Channel Perimeter Sediments and the Width to Depth Ratio

The channel perimeter sediments and the width to depth ratio have both been shown to have an association with the channel planform (see Chapter 2). From Schumm's (e.g. 1961a) work, one would expect that as the proportion of fine sediments in the channel perimeter decreases the channel should become wider and shallower. Table 5.1 summarises the statistically significant relations between the width to depth ratio and the sediment variables for the individual reaches and for all the reaches combined for the Sturgeon River. The details of the regressions and correlations are found in Appendix IVa.

In this analysis, Schumm's M, %SCBK, and %SCBD are used for comparison with relations in the literature. Because it is predominantly the clay component of the silt-clay fraction which is cohesive (Brady, 1974), the percent of clay in the banks, %CBK, and in the bed, %CBD are also used. The mean bank sediment size in mm, MBK, and the mean bed sediment size in mm, MBD, are used as well.

Schumm's width to depth ratio appears to be for a bankfull discharge (a 2.33 year recurrence interval). Consequently, it was hoped that (W/D)fb would provide relations similar to those found by Schumm. All of the relationships with the first-break-in-slope ratios are statistically significant (A-235 to A-248), but the signs are opposite to those expected from the literature. Thus, as the bed and bank sediments become finer, the channels become

TABLE 5.1. A diagram of the relationships between the width to depth ratios and the channel perimeter sediment variables for the Sturgeon River data. A positive sign, +, preceding the name of the reach or reaches indicates that the two variables are positively related and a negative sign, -, indicates that the two variables are negatively related for that data set.



wider and shallower. Also, in many cases, the exponents have relatively small magnitudes. The relations with bank sediment variables are statistically stronger than those with the bed sediment variables.

Some explanation is required of the discrepancies between Schumm's results and those for the Sturgeon River. Schumm's relation applies to stable, alluvial channels with little or no gravel in the channel perimeter. The Sturgeon River reaches may not be stable alluvial channels. Incision may be occurring which accounts for the relatively large "bankfull" stages (see Section 3.2.3), and, in some places, part or all of the channel perimeter is composed of non-fluvial sediments (bedrock or glacio-lacustrine sediments).

Although all the width to depth ratios are within the range of Schumm's (1961a) data, this is not the case for the sediment data, although for reaches A to C, the mean sediment sizes of most of the bed and bank samples are smaller than the range of median grain sizes given by Schumm. That is, although the percent silt and clay values are similar, the sediments for reaches A to C probably have a larger proportion of clay than do the sediments in Schumm's channels. For reaches E and F, although the bank sediments are sometimes within Schumm's range, the bed sediments are much coarser than are those from Schumm's rivers. The Reach D sediment data are entirely within Schumm's range for both the bed and bank samples. Although the Reach D sample size is small, all the statistically significant equations have exponents with signs in agreement with Schumm's equations, and the magnitudes of these exponents are generally comparable to those given in the literature (A-87, A-88, A-91 to A-94, A-97, A-98).

Thus, although statistically significant relationships are found for the Sturgeon River, these do not generally correspond to those presented by Schumm. The differences in material sizes in the two studies and possible contrasts in river stability are thought to be responsible for the lack of agreement. These results generally illustrate the dangers of generalising and extrapolating fluvial relationships beyond the conditions for which they are developed.

5.3 Planform and Channel Cross-sectional Characteristics

5.3.1 Meander Wavelength and Channel Width

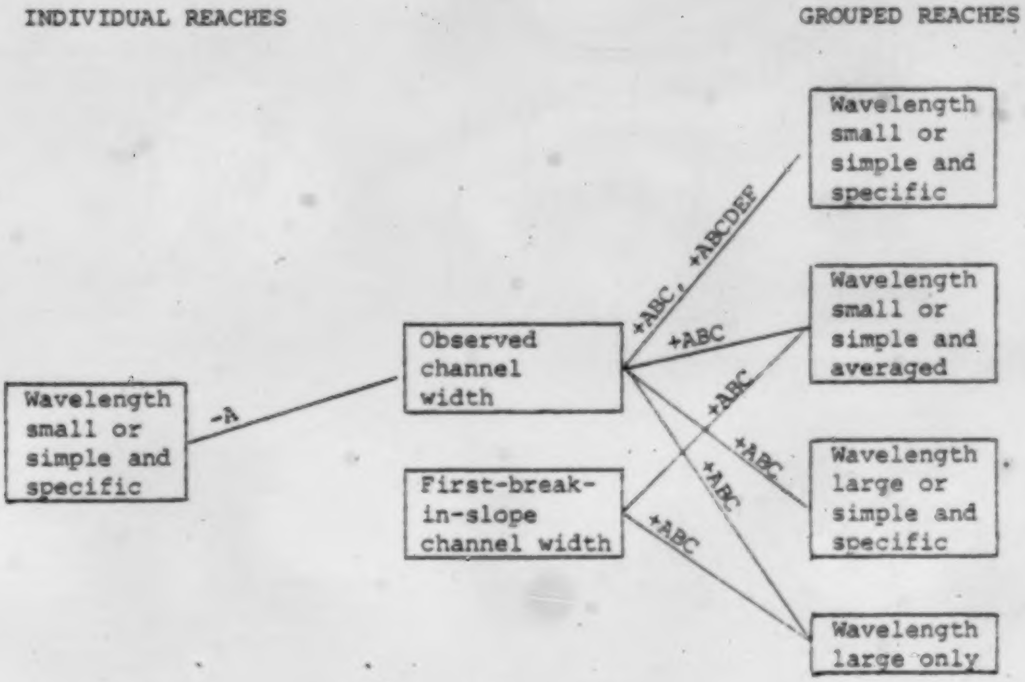
A number of investigators have found that meander wavelength, L, has a statistically strong linear relationship with channel width, W (Section 2.3). In general terms, one would expect the wavelengths of simple meanders and small meanders of the compound pattern to be positively related with some characteristic width, say the first-break-in-slope width, which controls the flow in such a way as to produce meanders of these wavelengths. The large meanders of the compound pattern should be positively related to some larger width, say the valley-flat break-in-slope width.

To help alleviate the problem of small sample sizes for the individual reaches, the data were grouped together. In contrast to the statistically weak results for the individual reaches from A to C (Table 5.2, Appendix IVb), when these data are grouped together, the exponents of the relations with observed channel width are statistically significant and close in magnitude to those given in the literature (B-16, B-18, B-20, B-22). The relations with Wfb are statistically weaker and the exponent of channel width is smaller for most of the equations (B-17, B-19, B-21).

When only the large meander data for reaches A, B, and C are regressed against either Wo (B-22) or Wfb (B-23), the exponents are positive, close to unity, and have strong statistical significances. When these meander data are regressed against the valley-flat break-in-slope channel width, Wvf, the relation is not statistically significant (B-24). This result is contrary to the expectation that the large meander wavelengths would be significantly related to Wvf and not to Wo or Wfb, and suggests that the large meanders are related to channel widths associated with relatively high frequency discharge events. This is contrary to any suggestion that the large meander form might be relict.

For the large or simple wavelength data of reaches A to C, the relation between wavelength and observed channel

TABLE 5.2. A diagram of those relationships between wavelength and channel width which are statistically significant for Sturgeon River data sets. A positive sign, +, preceding the name of the reach or reaches indicates that the two variables are positively related and a negative sign, -, indicates that the two variables are negatively related for that data set.


INDIVIDUAL REACHES
GROUPED REACHES
Wavelength small or simple and specific
-A
Observed channel width
First-break-in-slope channel width
+ABC, +ABCDEF
+ABC
+ABC
+ABC
+ABC
+ABC
Wavelength small or simple and specific
Wavelength small or simple and averaged
Wavelength large or simple and specific
Wavelength large only

width is quite close to linearity (B-20), whereas the relation between L and Wfb is statistically weak and the exponent of Wfb is small (B-21). This result is in agreement with the results for individual reaches.

When all the Sturgeon River data for the small or simple and specific wavelengths are grouped together, the regression equation for meander wavelength as a function of Wo (B-44) is significant and the exponent is similar to that given in the literature. When L is regressed as a function of Wfb, the resulting equation is not statistically significant and the exponent of Wfb is small (B-45).

Therefore, both the small and large meanders appear to be responding to high frequency discharges suggesting that an explanation of the meander forming process must relate both scales simultaneously to contemporary flow conditions.

There appear to be some differences between the relations for the reaches near Big Lake, reaches A to C, and those for the reaches further downstream, reaches E and F. When the small or simple and specific data for reaches A to C are combined, the exponent of Wo is strongly significant, positive, and close to, but smaller than, the magnitudes of the exponents in the literature (B-16). When data from reaches E and F are combined, the relation between L and either Wo or Wfb is positive but the exponents are large. However, the equations are significant only at the 80% level (B-41, B-42). Reaches A to C are characterised by low valley and channel slopes, and both channel beds and banks are often predominantly composed of silts and clays; reaches E and F have relatively steeper slopes, and coarser bed sediments.

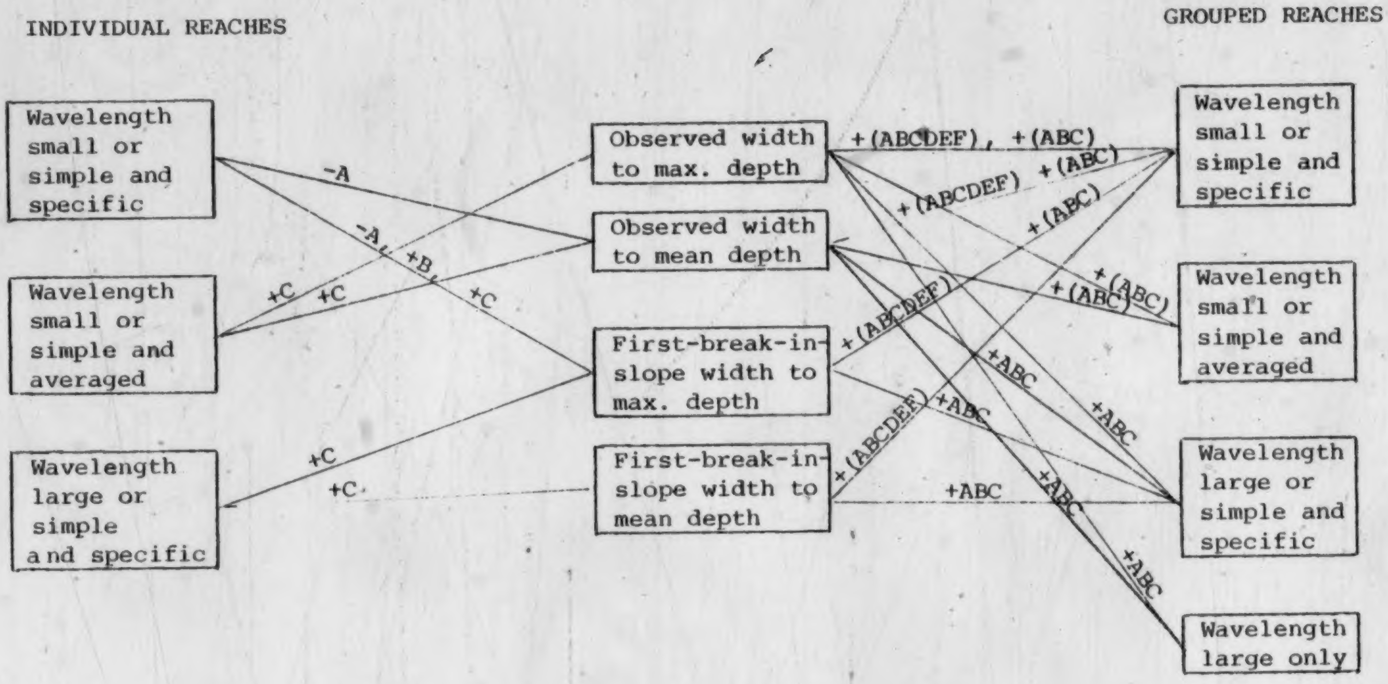
In conclusion, the statistically significant relations for the Sturgeon River data are usually near linear and positive, as expected from the literature. Leopold and Wolman (1960) used "mean bankfull" channel widths in their calculations of wavelength as a function of channel width. However, only a very few of the Sturgeon River data relations between wavelength and Wfb are statistically significant and very few are statistically better than the relations between L and Wo. Furthermore, the exponents of Wfb are generally not similar to those given in the literature.

5.3.2 Meander Wavelength and the Channel Width:Depth Ratio

From the literature (see Chapter 2), one would expect that narrower and deeper channels would have smaller meander wavelengths than wider and shallower channels. That is, wavelength should be positively related to the width:depth ratio.The relations for the Sturgeon River are found in Appendix IVc and Table 5.3 provides a summary of the statistically significant results.

The statistically significant relations for Reach A have negative signs(C-2, C-3) while those for reaches B and C are positive (C-15, C-21, C-22, C-23, C-29, C-30).

TABLE 5.3. A diagram of those relationships between wavelength and the width to depth ratios which are statistically significant for the Sturgeon River data sets. A positive sign, +, preceding the name of the reach or reaches indicates that the two variables are positively related and a negative sign, -, indicates that the two variables are negatively related for that data set.


INDIVIDUAL REACHES
GROUPED REACHES
Wavelength small or simple and specific
Wavelength small or simple and averaged
Wavelength large or simple and specific
Observed width to max. depth
Observed width to mean depth
First-break-in-slope width to max. depth
First-break-in-slope width to mean depth
Wavelength small or simple and specific
Wavelength small or simple and averaged
Wavelength large or simple and specific
Wavelength large only
-A
-A
+B
+C
+C
+C
+C
+C
+C
+(ABCDEF), +(ABC)
+(ABCDEF)
+(ABC)
+(ABC)
+(ABC)
+(ABC)
+(ABCDEF)
+(ABCDEF)
+ABC
+ABC
+ABC
+ABC
+ABC
+ABC

When the wavelength data for reaches A to C are grouped together, they are significantly and positively related to almost all width to depth ratios (C-31 to C-48). In addition, the exponents of the large or simple and specific grouped data are near unity while those of the simple and specific data are near 0.5.

Thus, as was the case for the relationships between meander wavelength and channel width, when the data from reaches A to C are grouped together, the relations usually are positive and statistically significant.

When the data from all the reaches for the simple or small and specific meander wavelengths are regressed against either the observed or the first-break-in-slope width:depth ratios, the resulting equations are highly significant (C-75 to C-78). The exponents are slightly larger for the first-break-in-slope width:depth data. For these equations, meander wavelength is a function of, roughly, the square root of the width:depth ratio. The exponents are also similar to those for most of the small or simple grouped data for reaches A to C (C-41 to C-48).

In conclusion, when the data are grouped, the statistically significant relations are positive and often near 0.5 for the small or simple wavelength data regressed on (W/D)o and somewhat larger when L is regressed on (W/D)fb. In most cases, the relations for the width:depth ratios have either about the same or stronger statistical significances and signs as the comparable relations for channel width. This suggests that the form of the channel may be as important or more important than the actual width in determining wavelength.

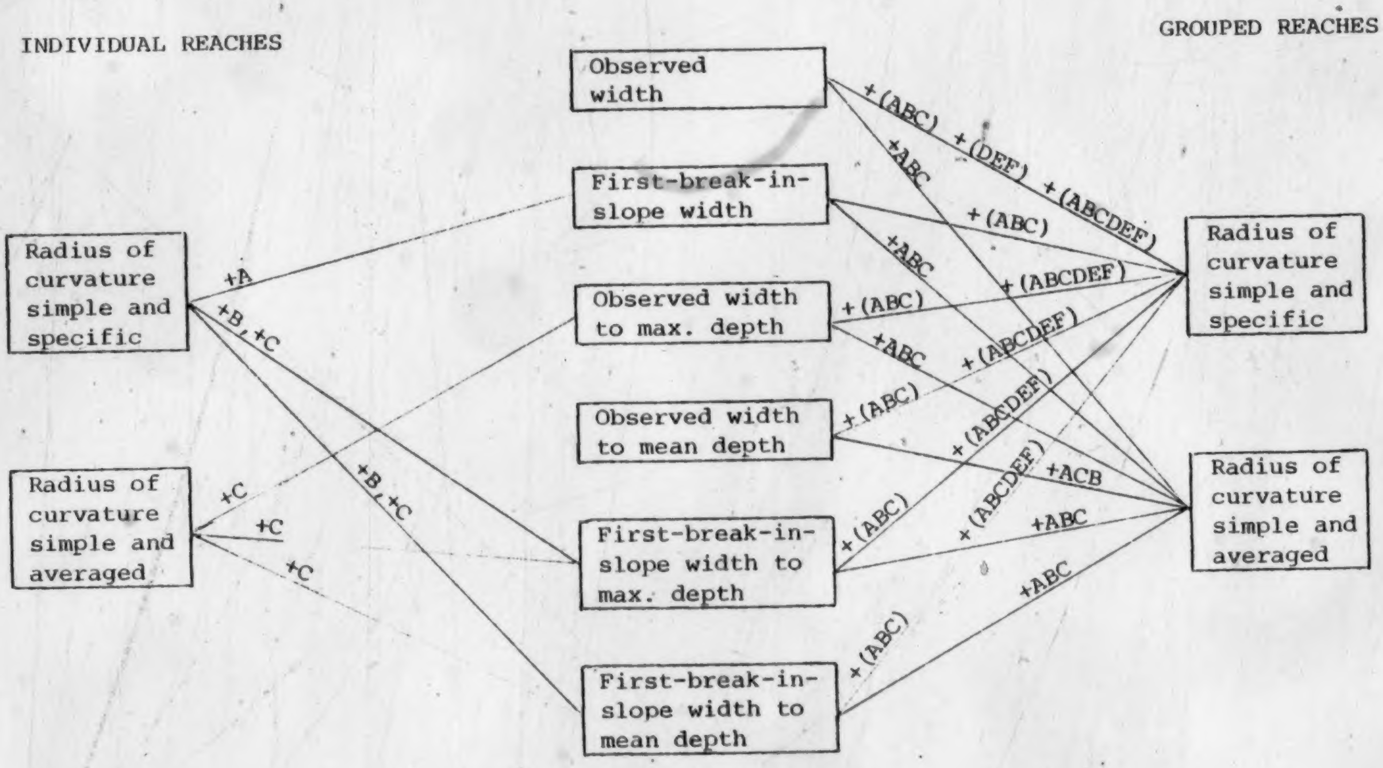
5.3.3 Radius of Curvature and Channel Width and Width to Depth

Generally, from the literature,one would expect the relation between radius of curvature, Rc, and width, W, to be positive and near linear (e.g. Leopold and Wolman, 1960).

The data in Appendix IVd and Table 5.4 reveal that highly statistically significant results with exponents close to one are obtained when the data for reaches A to C or for all the reaches are grouped together. Comparison of equations D-19, D-21, and D-25 with D-20, D-22, and D-26 shows that the results with the observed width, Wo, are somewhat statistically stronger, and the exponents of width are larger than those for the first-break-in-slope width, Wfb. The regression for the grouped data for reaches D, E, and F against Wo is statistically significant (D-23) but the exponent of Wo is relatively large.

For the observed widths, the data from reaches A to C combined have the smallest exponents (1.19, 1.03); the data from reaches D to F combined have the largest exponent (3.39); and the data from reaches A to F have an intermediate exponent (1.21). This suggests that the relationship between Rc and W may change depending on the characteristics of the channel, as does the relation between

TABLE 5.4. A diagram of those relationships between radius of curvature and width and between radius of curvature and width to depth which are statistically significant for the Sturgeon River data sets. A positive sign, +, preceding the name of the reach or reaches indicates that the two variables are positively related and negative sign, -, indicates that the two variables are negatively related for that data set.


INDIVIDUAL REACHES
GROUPED REACHES
Radius of curvature simple and specific
Radius of curvature simple and averaged
Observed width
First-break-in-slope width
Observed width to max. depth
Observed width to mean depth
First-break-in-slope width to max. depth
First-break-in-slope width to mean depth
Radius of curvature simple and specific
Radius of curvature simple and averaged
+A
+B, +C
+B, +C
+C
+C
+C
+(ABC)
+(DEF)
+(ABCDEF)
+ABC
+(ABC)
+ABC
+(ABCDEF)
+(ABC)
+ABC
+(ABCDEF)
+(ABC)
+(ABCDEF)
+(ABCDEF)
+ACB
+(ABC)
+ABC
+(ABC)
+ABC

wavelength and width.

Discussion in the literature also indicates the the Rc/W relationships depend on the individual characteristics of the rivers studied. Leopold and Wolman (1960) stated that for many rivers in the United States, the ratio of Rc/W is between 2 and 3. Hey (1976) determined that for the rivers Tweed and Wye, the radius of curvature was relatively large compared to the data from Leopold and Wolman. Hey proposed that the relation between Rc and W is dependent on the meander arc angle and hypothesised that Leopold and Wolman's data are from "well developed" meanders (p.482) with meander arc angles of approximately 150°. Meander arc angles for the rivers Tweed and Wye generally are smaller than this. For the Sturgeon River, the meander arc angles vary widely and the values of Rc/W are rarely between 2 and 3. However, they do not fit well with Hey's scheme where the plot of Rc as a function of width is contoured with arc angle values.

The relations between Rc and the width to depth ratio are summarised in Table 5.4. These regressions are statistically strong for the grouped data for reaches A to C (Appendix IVe, E-35 to E-42) and for all the reaches combined (E-47 to E-50). For the data from reaches A to C, the relations for the observed width to depth ratios (E-35, E-36, E-39, E-40) are statistically stronger and the exponents are usually closer to being linear than is the case for the relations for the comparable first-break-in-slope data (E-37, E-38, E-41, E-40). The strong relation with Wo supports the earlier conclusion that the channel forms of reaches A to C are related to contemporary, high frequency flow conditions.

5.3.4 Sinuosity, Width and Width to Depth

Appendices IVf and IVg and Table 5.5 present the regression results for sinuosity as a function of width and width:depth, respectively. Because the sample size for sinuosity is very small for individual reaches, regression equations have been calculated only for the grouped data.

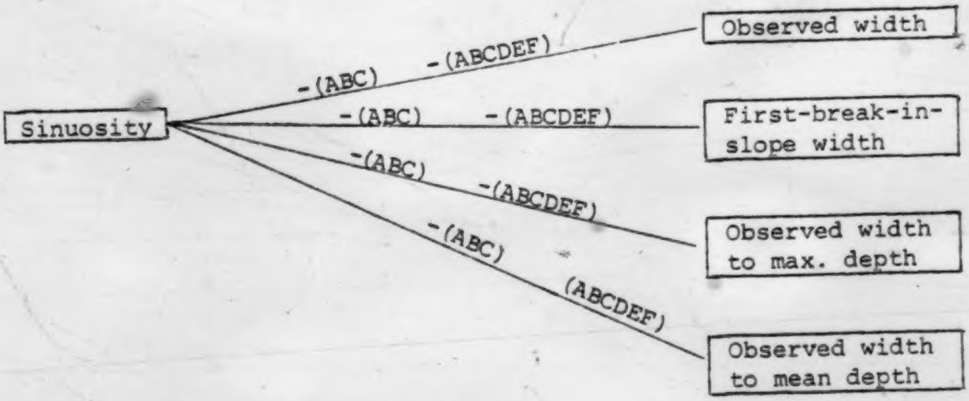
For sinuosity as a function of the width to depth ratio, the statistically significant relations are for the observed ratios for reaches A to C (G-1, G-2) and for all the reaches combined (G-9, G-10). In all cases (G-1 to G-9), the signs of the exponents are negative and the magnitudes of the exponents are small.

Schumm (1963) determined that, for rivers on the Great Plains which have ten percent or less of the bed sediment as coarse or coarser than coarse gravel:

$$\text{Sin} = 2.54\ (W/Dx)^{-0.27}$$

Schumm's equation compares favourably with the results obtained here in terms of the sign and the magnitude of the exponent. Furthermore, (W/Dx) consistently provides stronger statistical relations than (W/Dm) for comparable relations. Schumm's (1961a) width to depth ratio is probably for a bankfull value (mean annual flood). However, the bankfull relations for the Sturgeon River are poor. Once again, this

TABLE 5.5. A diagram of those relationships between sinuosity and width and sinuosity and the width to depth ratio which are statistically significant for the Sturgeon River data sets. A positive sign, +, preceding the name of the reach or reaches indicates that the two variables are positively related and a negative sign, -, indicates that the two variables are negatively related for that data set.


Sinuosity
-(ABC)
-(ABCDEF)
Observed width
-(ABC)
-(ABCDEF)
First-break-in-slope width
-(ABC)
-(ABCDEF)
Observed width to max. depth
-(ABC)
(ABCDEF)
Observed width to mean depth

probably results from difficulties in defining this stage and the fact that, in some reaches, bankfull stage is probably never achieved. Also, it is interesting to note that the relations with width alone rather than those for width:depth are statistically stronger for comparable data.

5.3.5 Amplitude and Channel Width and Width to Depth

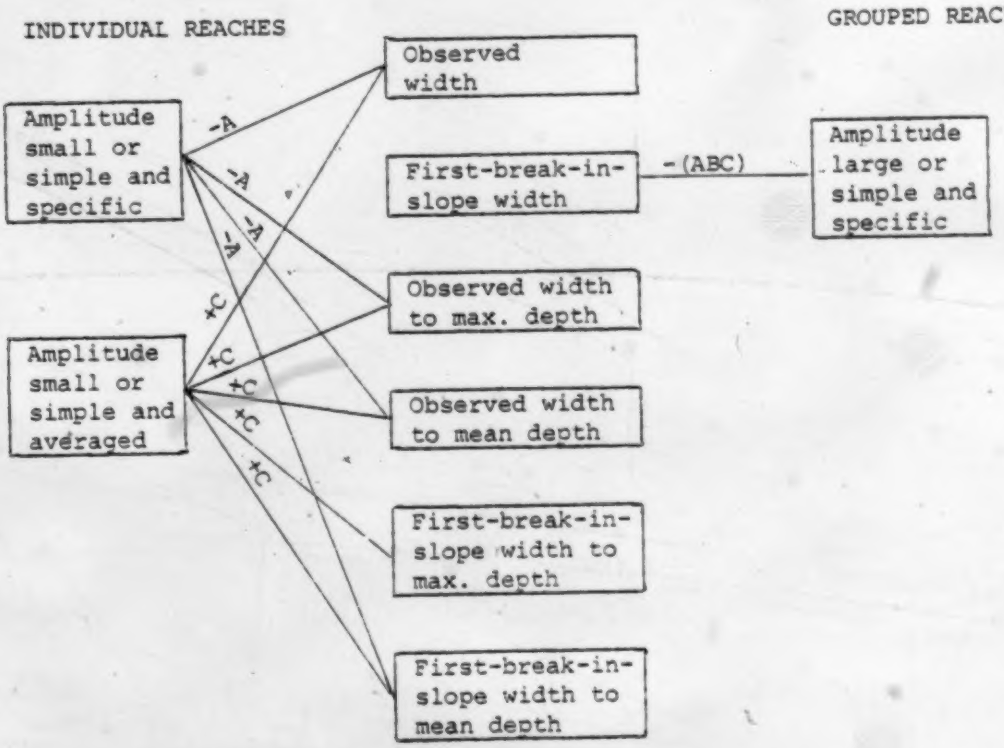
The relations between amplitude, Amp, and either channel width or width/depth are poor compared to the relations between the other planform variables and width. From the literature, one expects a positive, near linear although weak relation between amplitude and channel width (Leopold and Wolman, 1960; Ackers and Charlton, 1970a).

The generally weak and sometimes negative relations for the Sturgeon River between amplitude and width (Appendix IVh, Table 5.6 and width/depth (Appendix IVi) suggest that other factors are affecting the variations in amplitude. It seems probable that valley bottom width often, although not always, is an important factor (see Chapter 4).

5.3.6 Conclusions on Planform and Channel Cross-sectional Relations

The empirical relations from the literature show that radius of curvature, wavelength, and amplitude are each almost linearly related to channel width when data over several orders of magnitude are used. The equations for wavelength and radius of curvature are statistically better

TABLE 5.6. A diagram of those relationships between amplitude and width and between amplitude and width to depth which are statistically significant for the Sturgeon River data sets. A positive sign, +, preceding the name of the reach or reaches indicates that the two variables are positively related and a negative sign, -, indicates that the two variables are negatively related for that data set.


INDIVIDUAL REACHES
GROUPED REACHES
Amplitude small or simple and specific
Amplitude small or simple and averaged
Observed width
First-break-in-slope width
Observed width to max. depth
Observed width to mean depth
First-break-in-slope width to max. depth
First-break-in-slope width to mean depth
Amplitude large or simple and specific
-A
-A
-A
-A
+C
+C
+C
+C
+C
-(ABC)

than those for amplitude both in the literature and for the Sturgeon River data. Radius of curvature and wavelength both have near linear relationships with the observed width for reaches A to C combined and for reaches A to F combined. Thus, it appears that the channel is related to contemporary discharges, in this case high frequency, low magnitude discharges.

The equations for the first-break-in-slope data are generally much poorer than those for the observed data. It may be that Wfb is not a good approximation of bankfull channel width. If the width related to the dominant discharge could be calculated in some better way, the relationships between planform and width might be statistically stronger. Wfb is associated with a wide range of discharges depending on which portion of the channel is considered. Perhaps a width, like the observed width, associated with some given recurrence interval along the entire channel is necessary in order to produce equations which are comparable to those found in the literature.

Another important consideration when comparing the Sturgeon River data relationships with those given in the literature is the amount of scatter in the latter relations. That is, although the relationships are statistically strong over several orders of magnitude, for a small range in channel width values, wavelength, radius of curvature, and amplitude vary by large amounts (Hickin, 1980). Therefore, for individual reaches, the relations are not necessarily expected to correspond to those in the literature. Nevertheless, for some of the grouped data, the exponents are similar to those predicted even though the range in width and width to depth is small. The relationships between channel cross-sectional dimensions and curvature illustrate that one should not disregard the variations in the planform along a reach, as Leopold and Wolman have done by selecting a "representative" meander. If, as Hey (1976) hypothesised, the meander arc angle is an important factor, then Leopold and Wolman perhaps achieved stronger statistical relations by the selection of representative loops which, in effect, holds the arc angle nearly constant.

There appear to be some differences between the relationships for the grouped data for the low slope - fine sediment reaches and those for the grouped data from the higher slope - coarser sediment reaches. Generally, the latter have larger exponents than the former, indicating that the planform of the coarser, steeper reaches are more strongly affected by variations in channel cross-section.

An examination of Appendices IVa to IVi reveals that, in most cases, the equations for the width to mean depth ratio are very similar to those for the width to maximum depth ratio for the same data sets. Schumm (1961a) used the width:maximum depth ratio for his analysis but did not state why maximum depth is preferred over mean depth. The mean depth is a good approximation of the hydraulic radius (Ruhe, 1975) and so may have greater physical meaning than maximum depth. However, for the Sturgeon River data, the statistical difference is small in most cases.

The Sturgeon River has almost the same annual discharge at the gauge near St Albert as at the gauge near Fort Saskatchewan. Furthermore, the "observed" cross-sectional data were measured at approximately the same discharge level for reaches B to F. Thus, the downstream variations in the observed channel width are more a function of the channel cross-sectional form than the discharge variation. Consequently, it is not surprising that Wo and (W/D)o often produce similar statistical results in terms of the signs of the exponents and the statistical significances of the exponents for the grouped data.

In contrast, the first-break-in-slope width is not significantly correlated with either (W/Dx)fb ($r^2 = 0.003$) or (W/Dm)fb ($r^2 = 0.000002$). The variations in Wfb are probably more strongly affected by the variations in discharge than by the variations in cross-sectional form. Consequently, Wfb does not produce results which are similar to those for (W/D)fb. More importantly, Wfb can be considered as a surrogate measure of the discharge, call it Qfb, with which it is associated.

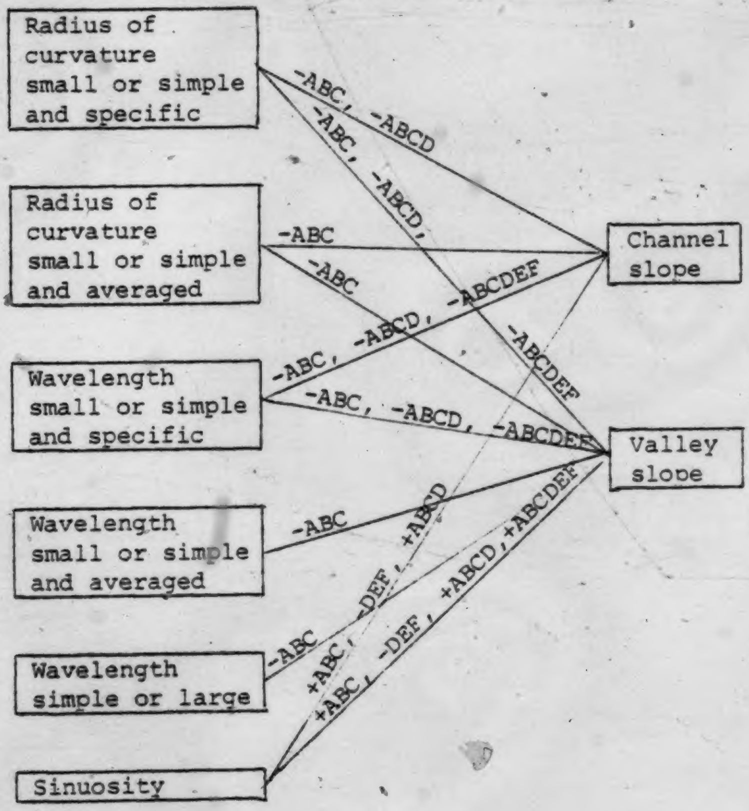
5.4 Channel Pattern and Slope

The slope data have very small sample sizes for the individual reaches. Therefore, regression analysis was applied only to the grouped data. Reach D occupies an intermediate position between reaches A to C and reaches E and F in some respects. Its channel and valley slopes are lower than those for reaches E and F, but higher than those for reaches A to C. Its bed sediments are finer than those of reaches E and F, but coarser than most of those found in reaches A to C. The Reach D data were grouped with the data from reaches A to C and E to F in order to increase the sample sizes of these data sets.

Meander amplitude, Amp, is not significantly related to channel slope, Sc, or to valley slope, Sv for any of the data sets (Appendix IVj, Table 5.7). Once again, one can conclude that other factors must be affecting the variations in amplitude.

Radius of curvature, Rc and meander wavelength, L, are significantly and negatively related to the channel and valley slope data for reaches A to C combined, A to D combined and A to F combined. (except for J-11, J-32, and J-39). Sinuosity is significantly and positively related to Sc and Sv for these data sets (J-7, J-8, J-30, J-31, J-38, J-39). That is, as the channel and valley slopes increase, the bends become tighter, the wavelengths shorter and the channel more sinuous. In contrast, for reaches D to F, sinuosity significantly decreases as both channel and valley

TABLE 5.7. A diagram of the relationships between planform and channel or valley slope which are statistically significant for the Sturgeon River data sets. A positive sign, +, preceding the name of the reach or reaches indicates that the two variables are positively related and a negative sign, -, indicates that the two variables are negatively related for that data set.


Radius of curvature small or simple and specific
Radius of curvature small or simple and averaged
Wavelength small or simple and specific
Wavelength small or simple and averaged
Wavelength simple or large
Sinuosity
Channel slope
Valley slope
-ABC, -ABCD
-ABC, -ABCD, -ABCDEF
-ABC
-ABC
-ABC, -ABCD, -ABCDEF
-ABC, -ABCD, -ABCDEF
-ABC
-ABC
+ABC, -DEF, +ABCD
+ABC, -DEF, +ABCD, +ABCDEF

slope increase (J-22, J-23).

Reaches A to C have low stream power values because of the very low channel slope. This agrees with findings in the literature that at low slopes, near the transition from straight to meandering, increases in sinuosity and tortuosity require an increase in slope (Morton and Donaldson, 1978). If one assumes that reaches E and F are closer to the transition from meandering to braiding than to the transition from straight to meandering, then the reduction of sinuosity with an increase in slope agrees with the trends noted in the literature (e.g. Schumm and Khan, 1972). The magnitudes of the exponents for the statistically significant equations are larger for reaches A to C combined than for all the reaches combined, for comparable relations. This is probably due to the fact that there are two opposing trends in the grouped data for all the reaches:

5.5 Planform and Sediment Characteristics

All planform variables are regressed against the percent of silt and clay in the channel bed and banks, %SCBK and %SCBD, and against the mean sediment sizes of the bed and banks, MBK and MBD. Schumm's M requires cross-sectional data and because so few cross-sections were measured, M was not calculated for Rc, L, or Amp. The sinuosity data have smaller sample sizes than the cross-sectional data so M was regressed on Sin. Because the percent of clay in the bed and in the banks did not consistently provide statistically strong relations with width/depth, it was decided to omit these two variables from the subsequent analysis.

To generalise the information discussed in Chapter 2, much of the literature indicates that, as the channel perimeter sediments become finer, meander wavelength and radius of curvature decrease and sinuosity increases, if other factors remain constant (Schumm, 1967; Ackers, 1980). However, Ferguson (1973) postulated that the effect of sediment may vary depending on where the channel is along the continuum of channel patterns.

For the wavelengths of the Sturgeon River (Appendix IVk), the strongest relations are for reaches A to F combined but the wavelength increases as the sediments become finer (Table 5.8). When all the Rc data (Table 5.9) are combined, the functions for the bank sediment variables are highly significant (Appendix IVl, L-30, L-32). However, the bends become tighter as the bank sediments become coarser.

Leopold and Wolman (1960) postulated that the generally poor relations between meander amplitude, Amp, and channel width are partly because Amp is strongly affected by bank characteristics. However, the regression equations for Amp as a function of channel perimeter sediment for the Sturgeon River data are poor (Table 5.10, Appendix IVm). For data from all the reaches combined, Amp has highly significant relationships for all the sediment variables (M-30 to M-33)

TABLE 5.8. A diagram of the relations between wavelength and the channel perimeter sediments which are statistically significant for the Sturgeon River data sets. A positive sign, +, preceding the name of the reach or reaches indicates that the two variables are positively related and a negative sign, -, indicates that the two variables are negatively related for that data set.

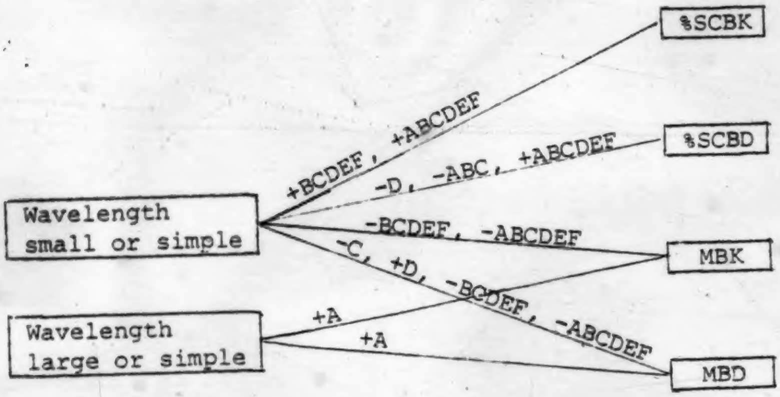


TABLE 5.9. A diagram of the relationships between radius of curvature and the channel perimeter sediments which are statistically significant for the Sturgeon River data sets. A positive sign, +, preceding the name of the reach or reaches indicates that the two variables are positively related and a negative sign, -, indicates that the two variables are negatively related for that data set.

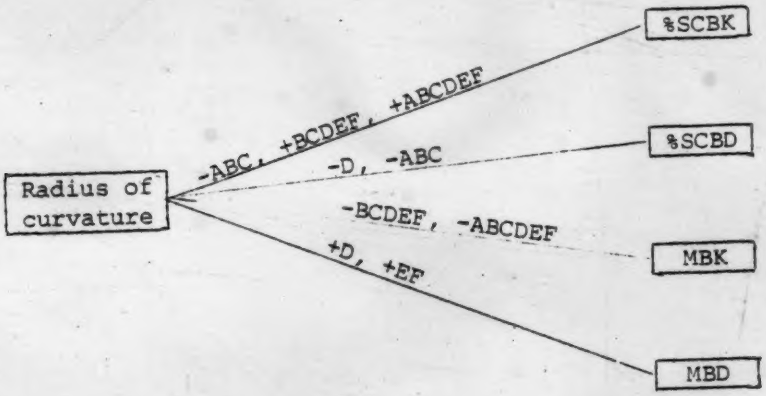
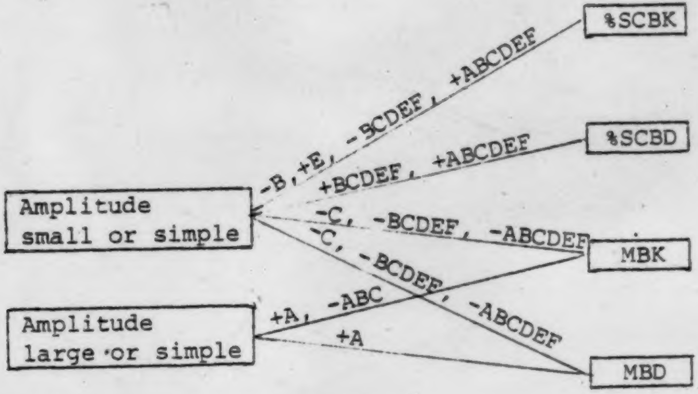


TABLE 5.10. A diagram of the relationships between amplitude and the channel perimeter sediments which are statistically significant for the Sturgeon River data sets. A positive sign, +, preceding the name of the reach or reaches indicates that the two variables are positively related and a negative sign, -, indicates that the two variables are negatively related for that data set.



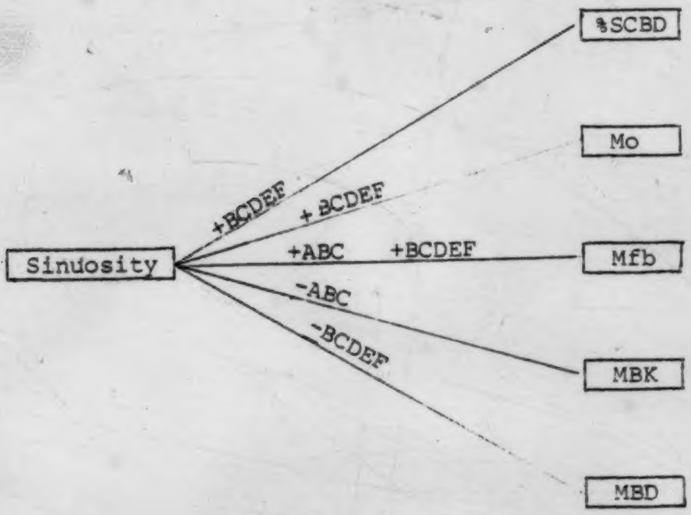
and increases as the channel perimeter sediments become finer.

Ferguson (1973) postulated that near the transition from straight to meandering, a reduction in the amount of fines in the channel perimeter would allow the stream to exhibit a greater meandering tendency. The large and simple data for Reach A show this pattern (L-45, L-46, M-47, M-48) as both amplitude and wavelength increase as the sediments become coarser. However, for the grouped data for reaches A to C, wavelength and amplitude become smaller and sinuosity increases as the proportion of fines increases.

Although Schumm found a very strong, positive relation ($r = 0.91$) between sinuosity and M, for the Sturgeon River data (Appendix IVn), sinuosity, Sin, has very poor statistical relationships with the sediment variables (Table 5.11).

It was thought that the opposing trend of the Reach A data might account for the poor statistical relations for the data from all reaches combined. Therefore, data from Reach A were omitted for part of the analysis (see also Morton and Donaldson, 1978). The statistical strengths of the relationships are improved for the sinuosity data when regressed on the bed sediment variables or Mfb (N-24, N-25, N-28). The signs of the exponents are in agreement with Schumm's work, but the magnitudes of the exponents are very small.

TABLE 5.11. A diagram of the relationships between sinuosity and the channel perimeter sediments which are statistically significant for the Sturgeon River data sets. A positive sign, +, preceding the name of the reach or reaches indicates that the two variables are positively related and a negative sign, -, indicates that the two variables are negatively related for the data set.



Generally, the bed and bank sediment variables show similar trends. The relationships for percent silt and clay variables are statistically stronger and the absolute magnitudes of the exponents are larger than those for the mean sediment size data.

The downstream portion of Reach C and the natural (that is before modification) pattern of Reach D both have contorted channel patterns with small wavelengths and small radii of curvature. Thus, the channel perimeter sediment samples for these contorted reaches may be sandy or clayey (see Chapter 4) but there is a common input of silty sediments through the undercutting and consequent calving of the Glacial Lake Edmonton sediments. This indicates that the sediment load should be measured in addition to the channel perimeter sediments. Also, the silt component may be important because sand particles and clay aggregates may be carried as bed or saltation load while the silt particles are carried as suspended load. Appendix IVo shows the results of regressions of the planform characteristics on a dummy variable for the (Glacial Lake Edmonton sediments / no Glacial Lake Edmonton sediments) condition. The equations are highly significant (O-1, O-2) for radius of curvature and wavelength. Both L and Rc are smaller for the portions along which the river undercuts Glacial Lake Edmonton sediments. Furthermore, on the slope - discharge diagrams (Figures 2.2, 2.3 and 2.4) low slope channels with either sandy beds or clayey beds plot in the same region of the graph and are both characterised by similar (usually tortuous) channel patterns. Therefore, bed sediment characteristics are not the determining factor in in this channel pattern.

In conclusion, the planform - sediment relationships often do not fit the relations described in the literature for the channel perimeter sediments. The variations in planform variables are dominated by other factors such as channel slope and simple relationships, like Schumm's, are not appropriate for this type of data.

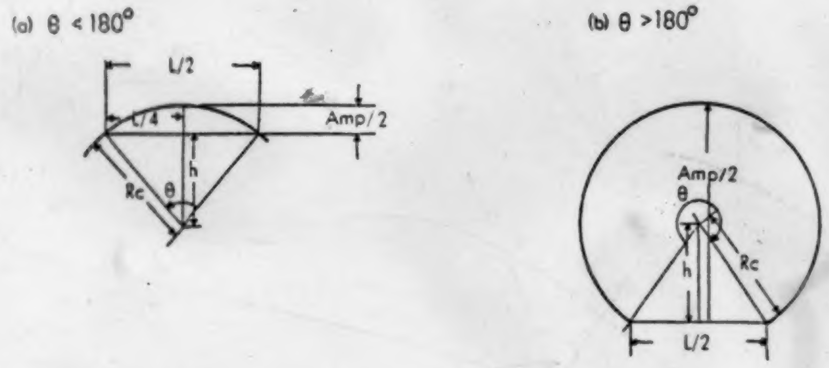
5.6 Planform Interrelations

According to Leopold and Wolman (1960), meander wavelength, L, has a positive, near linear relation with radius of curvature, Rc. Almost all the Sturgeon River data sets (Appendix IVp) have very strong, positive relationships between the two planform variables (except P-1). However, the exponents are all between 0.47 and 0.73.

Figure 5.1 shows the geometric relationship between L and Rc and meander amplitude, Amp. By simple geometrical principles, if Rc and the arc angle are specified, then L and Amp are determined. This indicates that arc angle would be a useful measure of channel planform.

To further investigate these relationships, a matrix of values of wavelength for various Rc and arc angle values was created (Table 5.12a). The values used are within the range

Figure 5.1 Geometrical relationships between the arc angle, θ, radius of curvature, Rc, wavelength, L, and amplitude, Amp.


(a) $\theta < 180^\circ$

(b) $\theta > 180^\circ$

Wavelength

$$(L/2)^2 = 2\,Rc^2 - 2\,Rc^2 \cos\theta \qquad \text{(Law of Cosines)}$$

$$\Rightarrow L = 2\sqrt{2\,Rc^2 - 2\,Rc^2 \cos\theta}$$

Amplitude

(a) $\theta < 180^\circ$ $$(Amp/2) = Rc - h = Rc - \sqrt{Rc^2 - (L/4)^2} \qquad \text{(Pythagorian Theorem)}$$

$$\Rightarrow Amp = 2\left(Rc - \sqrt{Rc^2 - (L/4)^2}\right)$$

(b) $\theta > 180^\circ$ $$(Amp/2) = Rc + h = Rc + \sqrt{Rc^2 - (L/4)^2}$$

$$\Rightarrow Amp = 2\,Rc + 2\sqrt{Rc^2 - (L/4)^2}$$

(c) $\theta = 180^\circ$ $$(Amp/2) = Rc$$

$$\Rightarrow Amp = 2\,Rc$$

TABLE 5.12. Wavelength, L, radius of curvature, Rc, and amplitude, Amp, all in metres, and their association with the arc angle, θ, in degrees.

(a) Calculated L for specific Rc and θ values.

Rc (m)	θ 120	100	80	60	30
100	346	306	258	200	104
200	692	612	514	400	208
300	1040	920	772	600	310
400	1386	1226	1028	800	414
500	1732	1532	1286	1000	518

(b) Calculated L for varied θ and specified Rc values.

Rc (m)	L (m)				
100	200	306	346	200	346
200	612	514	514	400	612
300	310	772	1040	772	772
400	1028	414	800	1028	800
500	1732	1286	1532	1732	518

(c) Calculated L values for varied θ and specified Rc, combined.

Rc	L
100	200
200	612
300	310
400	1028
500	1732
100	306
200	514
300	772
400	414
500	1286
100	346
200	514
300	1040
400	800
500	1532
100	200
200	400
300	772
400	1028
500	1732
100	346
200	612
300	772
400	800
500	518

TABLE 5.12d. The effects of the arc angle, θ, on the interrelations between wavelength and radius of curvature for the data from tables 5.12a, b, and c; the relations between radius of curvature, wavelength and amplitude and the arc angle for the Sturgeon River data of reaches A to C.

Ref. No.	Data set	Relation	Exponent	Student's t of exponent	Two-tailed significance of t (%)	Coefficient of determination, r^2	Sample size
	Data from 5.12a:						
1	θ = 120°	L=f(Rc)	1.00	1890	>>99.8	1.0	5
2	θ = 100°	"	1.00	1673	>>99.8	1.0	5
3	θ = 80°	"	1.00	1025	>>99.8	1.0	5
4	θ = 60°	"	1.00	1.04×10^8	>>99.8	1.0	5
5	θ = 30°	"	1.00	563	>>99.8	1.0	5
	Data from 5.12b:						
6		L=f(Rc)	1.16	2.731	90	0.713	5
7		"	0.66	1.931	80	0.554	5
8		"	0.85	4.396	95	0.866	5
9		"	1.31	12.741	99.8	0.982	5
10		"	0.36	1.576	50	0.453	5
	Data from 5.12c:						
11		L=f(Rc)	0.87	6.728	99.8	0.663	25
	Reaches A to C:						
12		Rc=f(θ)	-0.97	-8.571	99.8	0.498	76
13		L=f(θ)	-0.37	-3.330	99.8	0.130	76
14		Amp=f(θ)	0.950	8.501	99.8	0.494	76

of values found along the Sturgeon River. When the calculated L values are regressed on Rc, for a given arc angle, (that is, the columns of the matrix in Table 5.12a) the exponents of Rc are equal to one (5.12d-1 to 5.12d-5). Thus, if the meanders are selected so that they fall within a small range of arc angle values then the exponent of Rc will be near one. For their analysis, Leopold and Wolman selected a pair of symmetrical loops from each reach which they felt was representative of the entire reach. This may mean that, as Hey (1976) postulated, their data are for meander loops with a limited range of arc angle values. Leopold and Wolman's approach was not considered practical for the Sturgeon River because only a few data points would have been generated and because the selection of a representative loop would have been highly subjective particularly along reaches where the ranges in values for L and Rc are large. Furthermore, there is some question as to whether the selection of a representative loop is an appropriate method. Some investigators (Brice, 1973; Hickin, 1981) have proposed that the range in planform variation may be important.

Another matrix (Table 5.12b) was created to investigate the effects of a range of arc angle values. Values for each column were chosen randomly from values in the appropriate row of Table 5.12a. The exponents of Rc for the regressions using the data from Table 5.12b have a wide range of values from 0.36 to 1.31 and the statistical significances vary

(5.12d-6 to 5.12d-10). The data from Table 5.12b were rearranged to form Table 5.12c in order to create a larger sample size. The result is highly significant but the exponent is less than unity (5.12d-11).

Therefore, if meander loops are selected so that the arc angle variation is limited, then the result of the regression of L on Rc is predetermined. However, if the arc angle varies and there are trends in the variation of Rc with these variations in the arc angle, then the exponent of Rc will not be unity. If the arc angle increases as Rc increases, then the exponent of Rc will be greater than unity; and if the arc angle decreases as Rc increases, then the exponent of Rc will be less than unity. Thus, particularly for small data sets, the variations in the arc angle may be responsible for marked differences in the relationship between L and Rc. The arc angle was measured for 76 bends along reaches A to C. The minimum value is 33° and the maximum value is 253°. Therefore, there exists much variation in the arc angle. Also, Rc is negatively correlated with the arc angle, that is, Rc increases as the arc angle decreases (5.12d-12). Hence, from the above, it is expected that the exponent of Rc will be less than unity, which is the case.

Similarly, if the arc angle is held constant, the regression of Amp on L is linear and highly statistically significant, but if the arc angle varies then the exponent of L also varies as does the statistical significance of the relation. For the Sturgeon River data, the exponent of L varies greatly (P-10 to P-18) but the relationship is statistically significant for almost every reach.

In conclusion, the planform interrelations are dependent on the variations in the meander arc angle. Thus, Leopold and Wolman's result, for a nearly constant arc angle, is different from those of the Sturgeon River data which are based on a range of arc angles.

5.7 Multiple Regressions and Correlations for the Planform Variables

5.7.1 Introduction

For a natural channel, many factors may vary along a reach and the combined effects of these variations may result in variations in the channel pattern. Considering the effects of single variables, as one does with simple regression, ignores the fact that the channel pattern changes may be the result of changes in several variables. Simple regression of one variable on another assumes that the effects of all other variables have been held constant. The indirect effects of these other variables on the dependent variable of the simple regression may bias the regression and produce a "wrong" sign (Wonnacott and Wonnacott, 1972) that is *a priori* knowledge indicates the opposite sign is appropriate. Consequently, multiple regression analysis is used in this study in order to avoid such bias.

As discussed in Section 3.9.2, multiple regression analysis cannot be interpreted sensibly when the independent variables in the equation are correlated with each other. For this study, if two variables in a data set are significantly related at the 80% level or greater, then they are considered to be correlated and are not used together in multiple regression analysis for that data set. This restricts the combinations of variables and, in most cases, only two regressors could be used.

One should bear in mind that the sample sizes for some variables are not as large as those for other variables. A means of evaluating how the strength of a relationship is affected by the addition of a new variable is by the comparison of the values for the coefficient of determination before and after the variable is added (Section 3.9.1). Thus, multiple correlation is also used in the analysis. The relation is marked with an asterisk in the table if the R^2 value is significant at 90%. That is, if the population coefficient of determination can be said to be greater than zero with 90% or greater confidence.

The simple regressions showed that the results of regressions with width to maximum depth, (W/Dx), are very similar to those with width to mean depth, (W/Dm), for the same water level. Thus, for the multiple regressions, only (W/Dx) is used. The sediment variables used are the percent of silt and clay in the channel banks, %SCBK, and in the bed, %SCBD, and the mean bank sediment size, MBK, and bed sediment size, MBD. The specific rather than the averaged planform data are used.

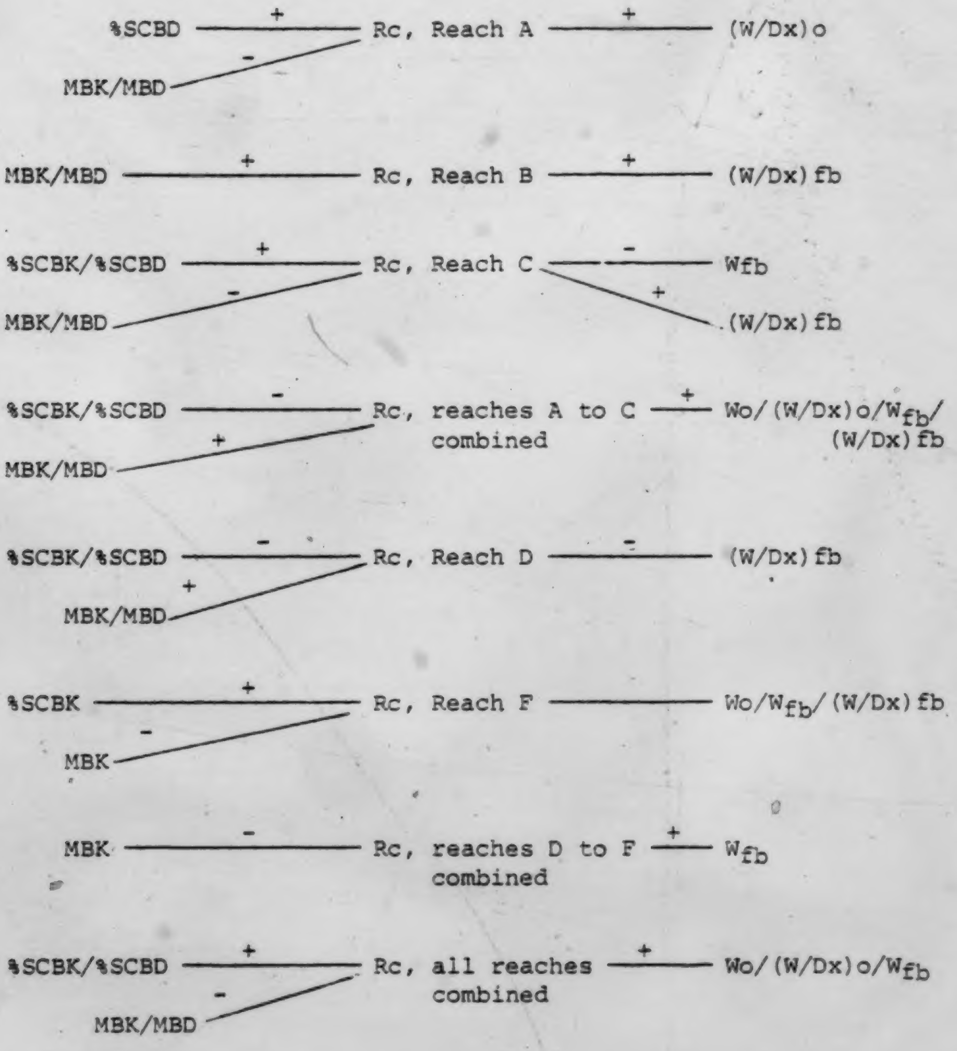
5.7.2 Relations for Radius of Curvature

Generally, for the individual reaches (Table 5.13), as the bank sediments become finer, and either the width or the width to depth ratio increases, Rc increases. Generally, Rc increases as the sediments remain about the same and one of Wo, Wfb, (W/Dx)o increases for reaches A to C combined. For reaches D, E, and F combined and for the data from all reaches combined, as the sediments become finer and one of Wo, Wfb, or (W/Dx)o increases, Rc increases (Q-58 and Q-62 to Q-68).

From the literature, Rc should increase as the sediments become finer (Ferguson, 1973) for reaches near the straight - meandering transition that is for reaches A to C of the Sturgeon River. Also, Rc should increase as the channel becomes wider and shallower (Morton and Donalson, 1978). To some extent, the relations for these reaches do show these trends Table 5.13). Rc increases as the sediments become finer for the data from reaches A and C. For the data from reaches A and B, and for reaches A to C combined, Rc increases as the width or width to depth ratios increase.

According to the literature, for channels closer to the meandering-braided transition, larger Rc values are

TABLE 5.13. A diagram of the statistically significant multiple regression relations with radius of curvature, Rc, for the Sturgeon River data sets. The '+' or '-' indicates the sign of the exponent when the variable or one of the variables is regressed on Rc.



associated with less sinuous streams which are, in turn, associated with coarser sediments and wider and shallower channels for a given discharge. Consequently, for reaches E and F, and perhaps reach D, which have relatively steeper slopes, one would expect that Rc would increase as the sediments become coarser and the channel wider and shallower. However, the former is only true for Reach D and the latter for Reach F and reaches D to F combined. The effect of artificial modifications on the planform - cross-section relations may account for the negative exponents of (W/Dx)fb for the Reach D data. That is, the planform has not readjusted as quickly as the cross-sectional form. It may well be that the unexpected relation with the sediment data is the result of the poor quality of the sediment data.

In all cases, slope decreases as Rc increases (Q-35, Q-36, Q-70, Q-71, Q-72). From the work of Schumm and Khan (1971, 1972), one would have expected this result for channels near the straight-meandering transition. Thus, the qualitative discussion (Chapter 4) and expectations based on the literature are supported by the quantitative data for reaches A to C. This result is not expected for the steeper reaches, E and F which probably illustrates that these reaches are not truly stable.

5.7.3 Relations for Meander Wavelength

For the statistically strong relationships (Table 5.14) of the data from reaches A to C combined, wavelength, L, increases as the sediment size increases and width or width to depth increases (Appendix IVr, R-51 to R-58). For the simple or large meander wavelength data of reaches A to C combined, the regression relationships are often strong (R-59 to R-77). Usually, the simple or large meander wavelength increases as slope decreases, Wo or (W/Dx) increases and as the bed sediment size becomes slightly coarser and the bank sediment size slightly finer. For the relationships which utilise the data from reaches D to F combined, wavelength increases as the bank sediments become finer, and W or W/Dx increases (R-102 to R-104). The t statistics for the sediment variables are the strongest. Many of the relations for the data from all the reaches combined are statistically significant (R-108 to R-115). The t statistics are usually large for all the variables. As the sediments become finer, and cross-sections become wider or relatively wider and shallower, the small wavelengths decrease.

The signs of the exponents of the sediment variables vary between the different reaches or groups of reaches for the small or simple meander data. In almost every case for both the simple or small and the simple or large meanders, L increases as either W or W/Dx increase. L increases as slope decreases but the relationships with slope are rarely

TABLE 5.14. A diagram of the statistically significant multiple regression relations with wavelength, L, for the Sturgeon River data sets. The '+' or '-' indicates the sign of the exponent when the variable or one of the variables is regressed on wavelength.

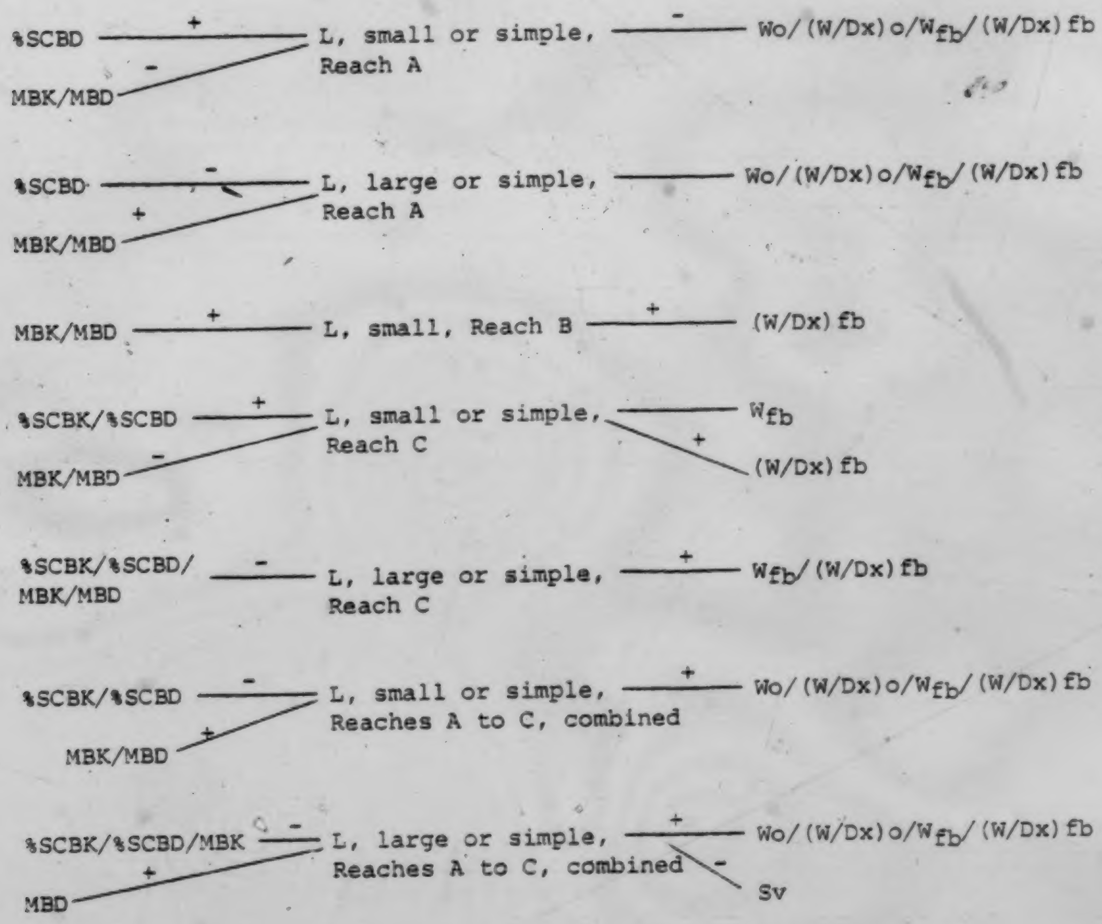
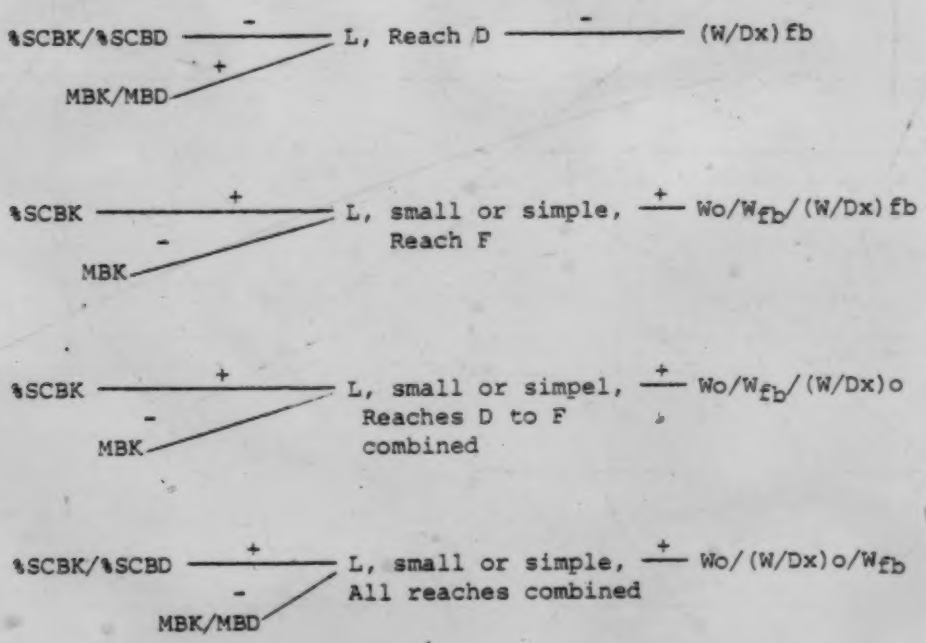


TABLE 5.14. Continued.



statistically significant.

That larger wavelengths are associated with larger channel widths, even though discharge does not vary greatly with distance downstream, can be considered as statistical support for the hypothesis that wavelength is controlled by width and that the relation between wavelength and discharge is an indirect one through width (Leopold and Wolman, 1960).

The positive relations with width and width to depth hold whether the meanders are simple, small or large except for data from Reach A (R-1 to R-24) and Reach D (R-84, R-85). Increases in wavelength are usually associated with channel straightening. However, along Reach A, the amplitude also becomes larger and so the meandering planform becomes better developed with distance downstream. Thus, the channel has a greater meandering tendency as the channel becomes narrower and deeper, as one would expect. The difference for the Reach D data is probably due to the artificial straightening. That is, the channel cross-section may be readjusted but not the planform.

The relationship between the simple or large meander wavelengths and the sediment variables is not consistent. For Reach A, the downstream growth of wavelength is strongly associated with a downstream coarsening in sediment. In contrast, for Reach C, the downstream disappearance of the large meanders is associated with a small downstream coarsening in sediment size. As a result, when data for reaches A to C are combined, many of the t statistics for the sediment variables are poor and the exponents small. Thus, although the initial development of the larger wavelengths along Reach A may be associated with coarser, more erodible sediments, the occurrence of compound meanders is not dependent on easily erodible sediments.

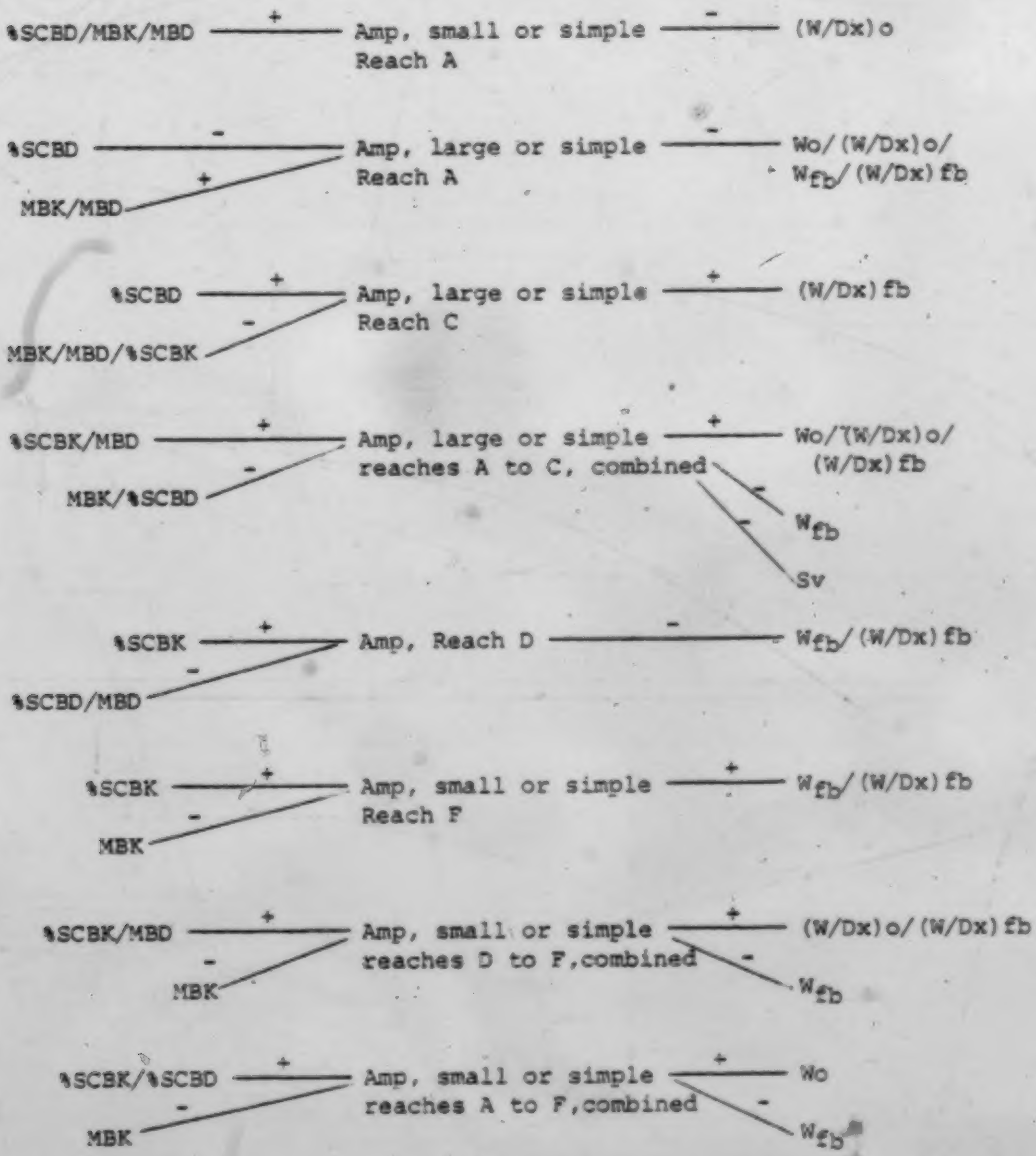
5.7.4 Relations for Meander Amplitude

The large or simple meander amplitudes for reaches A to C combined (Appendix IVs, Table 5.15) increase as the bank sediments become finer and the bed sediments coarser, valley slope decreases, Wfb decreases and Wo, (W/Dx)o and (W/Dx)fb increase (S-60, S-63, S-71, S-72, S-75 to S-77).

The ratio of (the large or simple amplitude) to (the large or simple wavelength) for the data from reaches A to C (not given in Appendix IVs) shows well the difference between the large amplitude meander portion and the channel pattern upstream and downstream of this portion. (see Chapter 4). Much of the variation in the ratio of amplitude to wavelength for the large or simple meanders of reaches A to C combined can be attributed to variations in valley bottom width.

When the amplitude data from reaches D, E, and F are combined, many of the multiple regressions have large t statistics for the sediment variables S-102 to S-106). Amplitude increases as the bank sediments become finer, as Wo, (W/Dx)o, or (W/Dx)fb increase or Wfb decreases.

TABLE 5.15. A diagram of the statistically significant multiple regression relations with amplitude, Amp, for the Sturgeon River data sets. The '+' or '-' indicates the sign of the exponent when the variable or one of the variables is regressed on Amp.



For the data from reaches A to F combined (S-108 to S-118), the t statistics are generally strong for the sediment and slope variables although the exponents for the slope and sediment variables are usually small. Amplitude increases as the sediments become finer, as slope decreases, as Wo increases and as Wfb decreases.

Generally, the variation in the small or simple amplitudes are often poorly and/or inconsistently (in terms of the sign of the exponent) related to the sediment variables. Even where the t statistics for the sediment variables are large, the exponents are usually small. This does not support the hypothesis of Leopold and Wolman (1960) that the poor relations between amplitude and channel width are the result of the effects of erosion characteristics of the channel perimeter. The t statistics for the width and the width to depth ratio are very often poor, especially for the small or simple data, although some relations, particularly those for the first-break-in-slope data, are statistically significant. This supports Leopold and Wolman's (1960) finding. Thus, the data available indicate that meander amplitude is not strongly controlled by the channel cross-section or the channel perimeter sediments. The valley bottom width at times acts as a control on amplitude.

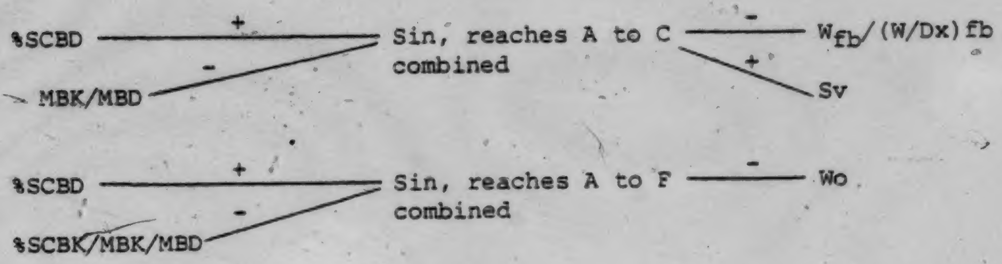
5.7.5 Relations for Sinuosity

The sinuosity data from reaches A to C combined have some statistically significant relations (Table 5.16) when the first-break-in-slope cross-sectional variables are regressors (Appendix IVt, T-7, T-9). For these regressions, sinuosity increases as the channel perimeter sediments become finer and Wfb or (W/Dx)fb becomes smaller. When valley slope is used in combination with the mean bed sediment size, the correlation with sinuosity is good (T-5). Sinuosity increases as the slope increases and the sediment remains about the same size.

According to Ferguson (1973), at very low slopes, near the transition from straight to meandering, a reduction in the amount of cohesive material in the channel perimeter leads to an increase in sinuosity, all other things being equal. At higher slopes, nearer to the meandering-braided transition, sinuosity should increase as the sediments become finer. Unfortunately, it is difficult to ascertain at what slope the change in this relation occurs for a given natural channel. For example, the highest sinuosities for reaches A to C occur where the finest material occurs, even though the slope is low.

This transition along reaches A to C to higher sinuosity is also associated with a small increase in slope. Morton and Donaldson (1978) found that at very low slopes, a small increase in slope can have marked effects on the channel pattern (Figure 4.7). This is confirmed by the

TABLE 5.16. A diagram of the statistically significant multiple regression relations with sinuosity, Sin, for the Sturgeon River data sets. The '+' or '-' indicates the sign of the exponent when the variable or one of the variables is regressed on Sin.



trends in the data for reaches A to C combined. It appears that the changes in slope may be more important for reaches A to C than changes in the percent of silt and clay in the channel perimeter and may "override" the effects of sediment size variations.

As slope increase, the channel becomes less sinuous for the data from reaches D, E and F. This is in agreement with relations in the literature for channels at higher slopes, although the Stureon River relations are often not statistically significant.

When the sinuosity data for all the reaches combined are regressed, the effects of the slope and sediment variables are minor. This is probably because of the opposing trends in their effects at different channel slopes and because of the poor quality of some of the data. Sinuosity increases as the width and the width to depth ratio decrease. This negative relation with sinuosity is consistent for all the multiple regressions shown in Appendix IVt. Thus, the channel becomes more sinuous as it becomes narrower and deeper, as Schumm (1963) determined and the magnitudes of the exponents for (W/Dx)o using the data from reaches A to F combined (T-20 to T-24) are close to -0.27, the value obtained by Schumm.

5.7.6 Summary of Multiple Regression Relationships

With respect to multiple regression analysis in general, additions of variables to simple regressions do improve the strengths of the coefficients of determination. However, the increases in the coefficients of determination are not always great, particularly when the simple correlations are weak. When the simple regressions are statistically significant, the signs of the exponents usually remain the same in the multiple regressions.

The literature leads one to expect that radius of curvature and wavelength will increase log-linearly with increasing channel width and sinuosity will decrease with increasing width to depth ratio. For most of the Sturgeon River reaches, the bends do, in fact, become longer and more gentle and the pattern less sinuous as the channel becomes wider. The results for amplitude are less consistent as expected from Leopold and Wolman (1960). The channel becomes straighter as the slope decreases for reaches A to C combined. This is as expected for low slope rivers from the literature (Morton and Donaldson, 1978).

Radius of curvature usually increases as the sediments become finer. The relationships with the sediment data are often poor for wavelength, amplitude and sinuosity, and the sign of the exponent may vary. The relation between planform and sediment may not be log-linear (Ferguson, 1973) and the effects of other variables, such as slope or valley bottom width on planform are probably more important than the effects of sediment variables.

Even in the multiple regression analysis, the regressors do not affect amplitude in a consistent manner from data set to data set. The effects of factors such as valley bottom width seem to be particularly important for amplitude.

5.8 Conclusions

First, a brief summary of the regression and correlation results is given below. Those relationships which are comparable with relations in the literature are given special attention. Following that, some general conclusions from the analysis are discussed.

The relations for amplitude are often poor for the Sturgeon River data sets. Relationships in the literature, especially those with field data also are statistically weak. Contrary to some suggestions, the Sturgeon River data do not indicate that sediment is a primary factor affecting amplitude. In fact, no single variable consistently affects amplitude strongly. Valley bottom width is an important control at times.

The simple relationships with channel width are near linear for radius of curvature and for wavelength for the grouped data from reaches A to C and from reaches A to F. These results are in agreement with Leopold and Wolman's (1960). It may be that the relationships with width are different for channels with relatively fine sediments and lower slopes than for those with coarser sediments and higher slopes. This is indicated by the fact that the exponents tend to be larger for the latter. The relatively strong relationships between wavelength and width are interesting if one accepts that discharge has been held nearly constant. It supports Leopold and Wolman's (1960) hypothesis that wavelength is indirectly related to discharge through its direct relation with width. That is, along the Sturgeon River, where the discharge doesn't vary, wavelength varies with channel width. For sinuosity, the relation with (W/Dx)o for the grouped data from reaches A to C or A to F is similar to that found by Schumm (1963).

The multiple regression relationships show that, for both wavelength and radius of curvature, the relations with width are fairly consistent in terms of the sign of the exponent. This is expected from the literature because L and Rc increase with channel width, no matter where the channel is along the straight meandering - braided continuum.

For the data from reaches A to C combined, A to D combined, and A to F combined, the bends become shorter and tighter and the pattern more sinuous as either the valley slope or the channel slope increases. This is expected for low slope channels (Schumm and Khan, 1972). For the data from reaches D to F combined, sinuosity decreases as the slope increases, as expected for channels at higher slopes (Schumm and Khan, 1972). Often either or both valley and channel slope are correlated with the other variables and so there are few multiple regressions with slope as a regressor. However, the trends in the multiple regressions with slope are similar to those in the simple regressions.

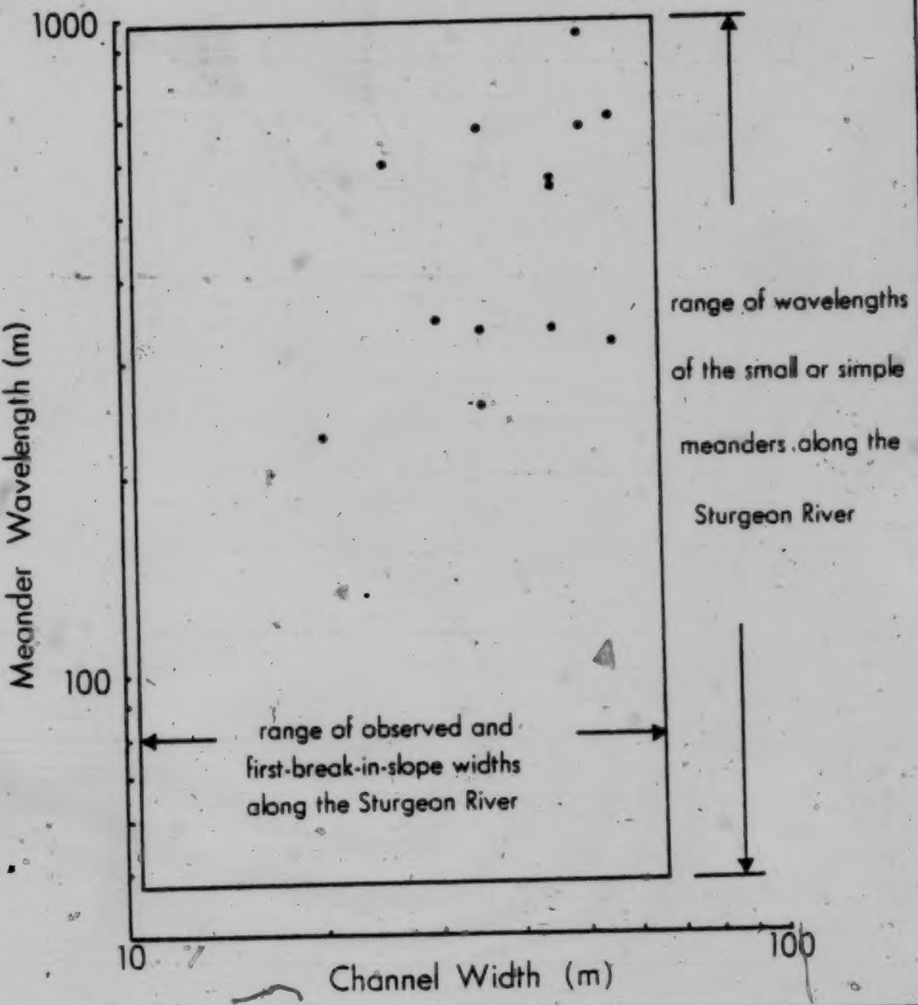
For the Sturgeon River data, the relationships with sediment are generally statistically weak for both the simple and multiple regressions although there are some significant relationships in individual cases. Radius of curvature tends to increase as the sediments become finer. Amplitude, wavelength and sinuosity often show weak relations with the sediments and/or relations whose sign varies from reach to reach. The statistically significant simple regressions for the data from reaches A to F combined show that radius of curvature, wavelength, and amplitude increase as the channel perimeter sediments become finer. This is what one would expect only for channels near the straight - meandering transition. The generally poor statistical results do not mean that the channel pattern is geomorphically unrelated to the sediment type. They may be in part attributed to the poor sediment sampling procedures. Also, sediment load might be more important statistically and geomorphically than channel perimeter sediment. Furthermore, variations in other variables may override the effects of the channel perimeter sediment in some instances.

During this study, several points were noted concerning the comparability of the Sturgeon River relations to those in the literature. The regression relationships given in the literature are statistically strong over several orders of magnitude but within a small range of variation in width, meander wavelength may vary substantially. A number of lines could be drawn through the data points from Leopold and Wolman (Figure 5.2) especially if only a few points are used. Values for most of the Sturgeon River data regressors usually fall within a small range. However, the relations between wavelength and observed width and radius of curvature and observed width are often near linear for the grouped data of reaches A to C and A to F.

Relationships obtained from laboratory data are achieved by holding all but a few of the variables constant. The complexity of natural channels makes comparison with laboratory streams difficult especially if some characteristics are varying so as to counteract the effects of changes in other variables. Nevertheless, the laboratory data do provide a simple basis for the study of natural channels, even though prediction of natural channel activity may not be possible in every case.

The relationships obtained from field data are not always directly comparable with the Sturgeon River data. For example, Schumm's (1961a) relationship between the width to depth ratio and M does not apply to much of the Sturgeon River data because the sediments are outside the range of Schumm's data. But other relationships, especially for some of the grouped data, are quite similar to results from field data reported in the literture.

Figure 5.2 Wavelength-width data points from Leopold and Wolman (1960) which are within the range of the Sturgeon River width data.



Some of the relationships given in the literature are not log-linear and so log-linear regression relationships may be weak where a significant range of data are considered. There is no clear way to determine exactly where a natural channel may be along the non log-linear relation. Fortunately, the Sturgeon River along reaches A to C goes through a transition in pattern from staight to sinuous so that its position on the curve can be more easily determined.

Many of the relations given in the literature are for stable channels flowing in alluvium. The relationships may be different for geologically young channels where not all the characteristics are adjusted to the present channel regime. The valley slope is a constant over a geologically short period of time and the channel slope is dependent to some degree on the valley slope. Valley bottom width, also a constant over short time intervals, may exert a strong influence when it confines the river's activity. The characteristics of both these variables may be relict from earlier river phases and formed under conditions different from those of the present day.

The planform variables used herein were selected so as to be comparable with those used in the literature. Different methods of measuring the planform variables, such as the selection of representative loops (Leopold and Wolman, 1960), may have provided stronger statistical relationships. Also, it was found in this study that other variables, such as the meander arc angle, may be useful in describing planform.

The observed channel width usually has relations similar to those for the observed width to depth ratio. This is probably because the observed water level is associated with a nearly constant discharge along a reach. Consequently, the variations in the observed width arise largely from variations in the channel form. In some cases, the exponents of the first-break-in-slope width, Wfb, have signs opposite to those for the first-break-in-slope width to depth ratio because discharge is not being held constant for these data. Consequently, the variations in Wfb are primarily a function of discharge variations.

One reason for selecting the Sturgeon River for this study was the fact that gauge data revealed that water discharge remains nearly constant between St Albert and the gauge near the mouth of the river. Thus, the variations in planform could be attributed to factors other than discharge. But is this actually the case? For example, if the first-break-in-slope water level represents a significant channel-forming discharge, call it Qfb, then this discharge should be used as a regressor as well. Nevertheless, it was shown that much of the variation in Wfb can probably be attributed to variations in Qfb and so Wfb could be considered as a surrogate to Qfb. Furthermore, the relations with observed width are often as good as or better than those with Wfb. Consequently, Qfb may not be the dominant discharge in terms of meander planform.

Some comments can also be made with respect to the sediment relationships. The field sampling of sediments was inadequate in some instances which very likely affected the results obtained. It was originally thought that the clay component, because of its cohesive character, might be more important than the silt-clay component of the sediment in promoting bank stabilisation and the formation of narrow and deep cross-sections. The results of the regression analysis indicate that a percent of silt and clay variable may be a good variable to describe channel perimeter cohesiveness in some cases. But, in other cases, it is important to know whether the channel perimeter is composed of clayey aggregates or silt particles. It is thought that these two types of fine sediment are transported in two different ways, accounting for the different channel patterns. This also leads to the conclusion that information concerning the type of sediment load may be important.

The physical significance of compound meanders is poorly understood (Brice, 1973). It is not known whether the relations for the small meanders or those for the large meanders or both should be considered to be comparable to the relationships for simple meanders given in the literature. The relationships for the large and simple data from reaches A to C are generally good. Some relations, for example those with the channel perimeter sediments, show opposing trends with respect to the planform variables, along different portions of this compound pattern. However, both the large and small meanders are statistically related to high frequency contemporary discharges.

In conclusion, the Sturgeon River data for radius of curvature, wavelength and sinuosity sometimes yield results very similar to those reported in the literature, particularly for the regressions with width. Despite some problems with the data, the relations with slope also agree with trends given in the literature. The relationships for amplitude are often poor because other variables such as valley bottom width account for much of the variation in places along the channel.

6. CONCLUSIONS

The aim of this study was to investigate the channel pattern of the Sturgeon River and the factors which affect it. One approach used in the literature to study such relations is log-linear regression analysis and this is the main method of analysis used here. There is usually much scatter in these empirical relations. This scatter may be explained by the effects of other variables on the planform. From the literature, the variables which are thought to affect the channel pattern are discharge, cross-sectional characteristics such as width or (width/depth), sediment characteristics such as the proportion of fine sediments in the channel perimeter, and channel and valley slope.

Data were collected from six reaches along the Sturgeon River between Big Lake and the North Saskatchewan River. This portion of the Sturgeon River was selected because gauge data indicate that water discharge remains approximately the same along this reach. Thus, one of the factors affecting planform is held constant. The six reaches were selected because they each show a downstream change in channel pattern. Data on the channel cross-sections, the channel perimeter sediments, the channel slopes and valley slopes were collected from these reaches. Valley bottom widths were also measured because the valley walls confine the meanders in some places. The downstream planform changes and their association with changes in the other variables were described qualitatively for each reach.

The channel pattern of Reach A changes from straight in the upstream portion to sinuous in the downstream portion. A compound meander pattern develops near the downstream end of Reach A. The river is wide, shallow and almost straight as it issues from Big Lake. Qualitative evidence indicates that the channel slope is extremely low here. This low slope prevents the river from carving an efficient channel cross-section and from developing helical flow and a meandering pattern. The slope becomes steeper as St Albert is approached. This steepening appears to be sufficient to induce meandering which persists through the central portion despite the low slope there. The downstream portion is slightly steeper and is also more sinuous, as predicted by Schumm and Khan (1972). The increasing sinuosity may also be associated with the decreasing cohesiveness and so increasing erodibility of the channel perimeter (Ferguson, 1973). The increasing sinuosity means that the simple meanders grow larger so that the pool spacing eventually becomes too large with respect to the channel width (Keller, 1972). A smaller pool spacing is achieved within this larger pattern by the development of small meanders within the large meanders.

The compound meander pattern occurs all along Reach B. The pattern is sinuous along the upstream and central portions. In the downstream portion, the large meanders have unusually large amplitudes. The downstream increase in slope may result in an increase in channel erosivity causing the increased amplitude. Also, the downstream increase in valley bottom width allows less restricted growth of meander amplitudes. The ridge-depressions and gently sloping point bars in the downstream portion are unusual for a channel flowing in fine sediments. These features may be associated with the transport of the silty clay aggregates as bed load rather than as suspended load. The variations in the small meanders are not related to variations in sediment size or cross-sectional characteristics.

The large amplitude meanders die out along Reach C and are replaced by simple meanders with a contorted pattern in the downstream portion. A contorted pattern is expected from the literature concerning low slope suspended load channels. The downstream portion of Reach C is characterised by steep convex banks, many cutoffs and an absence of scroll bars, which all indicate channel movement by avulsion. The tight bends along this portion have point benches deposited in separation zones at and just downstream of the point. The decrease in valley bottom width along Reach C may account for the disappearance of the large amplitude meanders. The input of predominantly silty sediments along the downstream portion of Reach C from the valley walls of Glacial Lake Edmonton sediments may mean that much of the load is in suspension at most discharges. The decrease in sinuosity may also be associated with the small decrease in slope along the reach.

"Enlarged bends", bends which are unusually wide and deep, are found where the planform is contorted. They have very small ratios of radius of curvature to width and limited erosion along the outside banks. The maximum velocity threads are along the inside banks so there are no well-developed point bars. In some cases, the river is impinging on the valley walls and the formation of these bends is probably due to abrupt angle eddy formation (Carey, 1969). In other cases, the river is not impinging on the valley walls where these bends occur. Small ratios of radius of curvature to width tend to produce separation zones along the concave banks and perhaps at high discharges the velocities in the separation zones are high enough for erosion along the concave banks.

The natural pattern of Reach D is contorted. The central portion was straightened in 1962-63. The contorted pattern is typical of other low slope channels in fine sediments. The straightened portion has a smaller proportion of fine sediments probably due to the increased channel slope. Also, the input of Glacial Lake Edmonton silts and clays has decreased because the diversion does not undercut the valley walls. The diverted portion appears to be reforming in a more sinuous pattern.

The upstream portion of Reach E has a contorted pattern and the downstream portion is almost straight. The contorted pattern is probably controlled by a low slope and a fine sediment load, similar to the conditions for the natural pattern of Reach D. The downstream portion is confined by the narrow bedrock valley. The coarser sediments in the downstream portion also require a steeper slope for erosion and transportation. By following a relatively straight course, the river creates a steep slope and so lateral erosion is limited.

The channel pattern is sinuous along the upstream portion of Reach F. The central portion is almost straight due to natural and artificial cutoffs. The downstream portion has a compound pattern. The limited data do not show any significant relationships between either sediment size or cross-sectional characteristics and the planform characteristics. The valley bottom confines the channel occasionally in the downstream portion but does not limit the meandering width in the upstream portion. It seems likely that the small meanders of the compound pattern develop in order to maintain a pool spacing similar to that in the upstream portion. However, no explanation was found for the development of the large meanders based on the available data. Some of the evidence indicates that a meandering pattern is reforming in the central portion.

Log-linear simple and multiple regressions and simple and multiple correlations were used to analyse the data collected from the six reaches. The results of this analysis can be briefly summarised in general terms.

The simple relations with channel width are near linear for radius of curvature and wavelength, as predicted by

Leopold and Wolman (1960), for the grouped data from reaches A to C and from A to F. The exponents are larger for the grouped data from reaches D to F, suggesting that the relation with width is different for channels with relatively fine sediments and low slopes as compared to those with steeper slopes and coarser sediments. The sign of the exponent is not consistent for the relations with amplitude. The relationship between sinuosity and the ratio of the observed width to the maximum depth for the observed water level is similar to that found by Schumm (1963) when the grouped data from reaches A to C and A to F are used. The multiple regression results show that wavelength and radius of curvature are usually positively related to width. This is expected from the literature: wavelength and radius of curvature increase with channel width no matter where the channel is along the straight - meandering - braided continuum. These results also support the hypothesis of Leopold and Wolman (1960) that wavelength is directly related to width and only indirectly related to discharge through its relation with width. That is, along the Sturgeon River the discharge does not vary greatly and wavelength still varies with width.

The often weak and/or negative relationship between amplitude and width also supports the findings of Leopold and Wolman (1960). In contrast, there is no support from the Sturgeon River data of their hypothesis that the variations in amplitude can be related to variations in bank erodibility, assuming that the bank sediment characteristics are related to bank erodibility. The relationships between amplitude and the sediment variables are often weak and/or inconsistent in terms of the sign of the exponent. In places, amplitude is strongly affected by the valley bottom width which biasses the results with other variables.

Wavelength and sinuosity also have poor statistical relations with the sediment variables. The statistically significant simple regressions for the data from reaches A to F show that radius of curvature, wavelength, and amplitude increase as the sediments become finer. This is what one would expect only for channels near the straight - meandering transition, i.e. only for reaches A to C.

The generally poor statistical relations with the sediment data are probably due in part to the poor quality of some of the sediment data. In addition, the relationshipss with sediment may not be log-linear (Ferguson, 1973). In some cases, the effects of variations in the sediment variables may be overridden by stronger opposing effects of variations in other characteristics, such as slope. Also, evidence from this study indicates that a sediment load variable might provide stronger relations than the channel perimeter sediments.

The relation between slope and channel pattern also is not log-linear For the data from reaches A to C, A to D, and A to F, the bends become shorter and tighter, and the pattern more sinuous as either the valley or channel slope increases as expected for low slope channels (Morton and Donaldson, 1978). For the data from reaches D to F combined, sinuosity decreases as the slope increases, as predicted by Schumm and Khan (1972) for channels nearer to the meandering - braided transition. Trends seen in the multiple regressions with slope are similar to those in the simple regressions.

Some general comments can be made concerning the variables used. The width to maximum depth ratio was found to yield results very similar to those for the width to mean depth ratio. The observed width to depth ratio and the observed width varied in similar fashions. A different method of measuring "bankfull" might have improved the statistical relationships with the cross-sectional variables. The percent of silt and clay is a useful means of describing bank characteristics in some cases. However, an increase in this value does not necessarily mean an increase in channel perimeter cohesiveness. Also, when the percent of clay is very high, much of the load may be carried as aggregates rather than as discrete particles. Of the planform variables used, radius or curvature and wavelength usually provided the statistically strongest results. The relations with amplitude were very often weak indicating that other factors affect its variation. There are indications from the work done that meander arc angle and arc length might be useful planform variables.

As important as the detailed results from the analysis are some of the conlusions as to the usefulness of log-linear regression for this type of study. Log-linear relations may be appropriate for only parts of the curve describing the whole relationship. Some of the non-linear relations are affected by the channel's position along the straight - meandering - braided continuum and this is difficult to determine this for a natural channel unless it actually goes through such a transition. Much of this study has concentrated on comparing the Sturgeon River data relations with those from the literature. However, in some cases, the data measurement methods differ or the data are collected from laboratory or natural channels where certain characteristics are held constant or near constant. Some planform relations in the literature are strong only over several orders of magnitude. In contrast, much of the Sturgeon River data is within one or two orders of magnitude and so does not always yield relations which are statistically similar to those for data with a larger range of magnitudes. Despite these problems, the larger sample sizes usually generate relations with trends similar to those described in the literature.

Qualitative considerations of the study reaches indicated some possibilities for explanation of the observed channel pattern changes. The quantitative analysis revealed that log-linear regression should be used with care because of the complexities of variations along a natural channel and the non log-linear relationships for some variables. Channel slope can be a very important variable in determining channel pattern especially at thresholds such as the pattern transition from straight to tortuous. Valley bottom width also exerts an important control on the planform at times. The channel perimeter sediments have some effect on the channel pattern but rarely seem to be the determining factor. Although over short reaches, width and width to depth do not always exhibit a strong effect on channel pattern, there appears to be an overall control of planform dimensions by width and channel form.

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APPENDIX I - Laboratory Procedures for Sediment Size Analysis

This procedure is modified from the American Society for Testing and Materials (1978) procedure D422-63(1972).

Preliminary procedures

1.Prepare hydrometer bath and allow to come to room temperature.

2.Prepare a 4% solution of sodium metaphosphate using distilled water.

3. Take 125 ml of 4% sodium metaphosphate solution and make up to 1000 ml with distilled water. Place solution in a sedimentation cylinder and place cylinder in hydrometer bath. Allow solution to come to temperature of bath. Record temperature. Insert hydrometer into cylinder and record reading at the top of the meniscus.

Preparation of Sample

4. Air dry field samples.

5. Break up aggregates with a mortar and pestle, being careful not to break up small stones.

6. Mix sample thoroughly and quarter it into approximately the amount required for analysis. Use about 100 g for sandy samples and 50 to 60 g for silty or clayey samples.

7. Weigh the sample and record the weight to two decimal places.

Separation of Coarser Fraction

8. Using a 2 mm sieve, separate the portion retained on the sieve. Grind any aggregates remaining on the sieve and pass the sediment through the sieve again. These large particles set up turbulence as they fall which disrupts the settling of the other particles.
9. Wash the sample remaining on the 2 mm sieve with distilled water to remove any fines. Be sure to retain these fines, let dry and mix with those fines which passed through the sieve in step 8.
10. Dry and weigh the portion remaining on the 2 mm sieve. Use sieving procedure described below for these samples.

Hydrometer Analysis

11. Place the sediment which passed through the 2 mm sieve in a 250 ml beaker and add 125 ml of the 4% solution of sodium metaphosphate. Stir until sample is thoroughly wetted.
12. Allow sample to soak for at least 16 hours.
13. After soaking, transfer slurry to dispersion cup, washing the residue out of the beaker and into the

dispersion cup with distilled water.

14. Attach dispersion cup to mechanical mixer and mix slurry for one minute.

15. Transfer slurry to sedimentation cylinder and make up volume to 1000 ml with distilled water.

16. Stir vigorously with mixing rod and let stand for 24 hours.

17. Check for flocculation, which appears as a "mushy" layer at the bottom of the cylinder.

18. If flocculation is present, begin again at step 6 and try, successively and then in combination:

    a. 5 minute mixing time,

    b. stronger dispersant concentration, up to 10% of sodium metaphosphate, remembering to make a new control cylinder (step 2) using the proper concentration, and

    c. smaller sample size, down to about 40 g,

until flocculation does not occur.

19. If no flocculation can be seen, place sedimentation cylinder in the hydrometer bath and allow the slurry to come to the temperature of the bath.

20. Prepare data sheets, with times of readings.

21. Stir cylinder for one minute with a mixing rod, that is about 60 up and down motions.

22. Take hydrometer readings at 2, 5, 15, 30, 60, 250, and 1440 minutes after stirring is finished. Careful timing is required especially for the first reading.

23. In some cases, the surface of the slurry will be foamy after stirring (step 21). To permit accurate reading of the first few hydrometer measurements, add a few drops of amyl alcohol (Bouyoucos, 1936).

24. To take hydrometer readings, carefully insert hydrometer about 20 to 25 seconds before reading is to be taken. Read the hydrometer scale at the top of the meniscus and record the reading. Carefully remove the hydrometer and clean it off with distilled water.

25. After each reading, record the temperature of the water bath.

26. After the final hydrometer reading, transfer the slurry to a 0.062 mm sieve and wash the sediment until the water passing through it is clean.

27. Let dry the material coarser than 0.062 mm.

Sieving Analysis

28. Weigh and record weight of dried sediment coarser than 0.062 mm.

29. Using a nest of sieves at 1/2 phi intervals, pour the sediment through the top sieve, making sure that the collection pan is at the bottom of the nest.

30. Shake the nest of sieves for 10 minutes.

31. Weigh the amount retained on each sieve and the collection pan and check the total weight to make sure that it is closely equal to the original total weight

(step 28).

Calculations

32. Calculate the percent weight data for the sieved portions of the sample. Divide the mass on a sieve by the total mass of the original sample (step 7) and multiply by 100.

33. Calculate the percent of soil in suspension. The hydrometer 151H was used for this study. The composite correction for temperature, dispersant and meniscus is:

(Actual hydrometer reading) - 1 = Corrected Reading

The formula for the calculation is:

$$P = ((100000/W) \times (G/G-G_1)) \times (R-G_1)$$

where:

P = percent of soil remaining in suspension at the level at which the hydrometer measures the density of the suspension,

R = hydrometer reading, with correction applied,

W = (dry sediment mass/percent passing through the 2 mm sieve) x 100 , in g,

G = specific gravity of the soil particles (assume for convenience that G is 2.65 g/cm^3), in g/cm^3, and

G_1 = specific gravity of the liquid in which the particles are suspended. Use $G_1 = 1$.

34. Calculate the diameter of the soil particles in suspension using:

$$d = K\sqrt{(L/T)}$$

where:

d = particle diameter in mm,

L = distance from the surface of the suspension to the level at which the density of the suspension is being measured (from the hydrometer reading, using Tables).

T = time interval from the beginning of sedimentation to the time of reading, in minutes, and

K = a constant, depending on the temperature of the suspension, and the specific gravity of the particles (assume 2.65 g/cm^3) from Tables.

27. Plot the cumulative percent frequency data against sediment size. If any large "kicks" occur in the silt sized data, redo the hydrometer analysis, as the kicks may indicate flocculation has occurred. The initial hydrometer measurement at 2 minutes may be inaccurate because the hydrometer reading changes very rapidly during the first few minutes of settling which may also cause a kick in the curve. If a kick occurs consistently for one particular sieve size, this may mean that the sieve is not accurate, and perhaps has had some damage done to the screen.

APPENDIX II - Radius of curvature, Rc, wavelength, L, and amplitude, Amp, of the simple and small meanders of the Sturgeon River reaches. The data for reaches D and F are the natural planform values.

Reach		Rc (m)	L (m)	Amp (m)	Distance downstream from Big Lake (km)
A		342.9	548.6	61.0	1.52
		342.9	396.2	30.4	2.77
		342.9	487.6	48.8	3.09
		342.9	640.0	79.2	3.41
		247.65	701.0	140.2	3.89
		342.9	609.6	61.0	4.22
		190.5	457.2	73.2	4.54
		152.4	487.6	109.8	4.70
		209.5	670.6	170.6	5.18
	Small meanders	209.55	731.6	225.6	5.66
		304.75	426.8	18.2	6.15
		152.4	335.2	48.8	6.31
B		152.4	396.2	61.0	6.47
		171.45	213.4	18.2	6.63
		142.9	274.4	30.4	6.79
		190.5	396.2	48.8	6.95
		247.65	884.0	268.2	7.27
		85.7	213.4	42.6	7.60
		85.7	243.8	36.6	7.76
		114.3	243.8	30.4	7.92
		114.3	243.8	30.4	8.08
		190.5	609.6	152.4	8.24
		228.6	609.6	91.4	8.72
	Large amplitude meanders portion	80.95	274.4	61.0	9.04
		30.95	152.4	61.0	9.21
		304.75	579.2	61.0	9.37
		247.65	457.2	42.6	9.69
		61.9	225.6	79.2	9.85
		304.8	944.8	231.6	10.49
		247.65	487.6	61.0	10.98
C		171.45	335.2	42.6	11.14
		47.6	182.8	91.4	11.30
		152.4	274.4	18.2	11.46
		133.35	304.8	36.6	11.94
		142.9	426.8	439.0	12.26
		152.4	243.8	24.4	12.58
		152.4	274.4	30.4	12.74
		133.35	518.2	195.0	12.90
		133.35	365.8	73.2	13.23
		123.8	182.8	30.4	13.37
		57.15	213.4	36.6	13.55
		109.55	426.8	134.2	13.71
		228.6	579.2	91.4	13.87
		57.15	213.4	91.4	14.03
		57.15	243.8	97.6	14.35
		152.4	274.4	30.4	14.67
		152.4	243.8	12.2	14.83
		42.85	152.4	61.0	15.00
		45.25	182.8	103.6	15.16
		142.9	365.8	103.6	15.32
		133.35	274.4	36.6	15.48
		57.15	182.8	73.2	15.64
		266.7	378	30.4	15.80
		47.6	182.8	109.8	15.96
		109.55	426.8	182.8	16.12
		33.35	122.0	103.6	16.28
		247.65	518.2	61.0	16.44
C		52.4	182.8	61.0	16.60
		142.9	182.8	18.2	16.77
		42.85	152.4	30.4	16.93
		40.5	182.8	91.4	17.09
		228.6	487.6	67.0	17.20
		133.35	243.8	18.2	17.41
		42.85	122.0	18.2	17.57
		33.35	213.4	36.6	17.73
		57.15	182.8	182.8	17.89
		209.55	304.8	18.2	18.05
		66.7	243.8	79.2	18.21
		23.8	91.4	48.8	18.37
		45.25	152.4	61.0	18.54
		123.85	396.2	103.6	18.70
		23.8	61.0	79.2	18.86
		66.7	274.4	122.0	19.02
		23.8	91.4	73.2	19.18
		142.9	365.8	61.0	19.34
		50.0	182.8	42.6	19.50
D		62	216	60	53.29
		36	108	36	53.29
		67	168	24	53.45
		24	96	24	53.61
		190	192	12	53.61
		29	96	48	53.61
		171	192	24	53.61
		31	108	36	53.77
		81	132	36	53.93
		21	72	36	54.09
		110	240	36	54.09
		81	132	24	54.09
		19	72	36	54.09
		190	600	120	54.09
		19	48	12	54.09
		38	132	48	54.26
		24	84	24	54.26
		29	108	48	54.26
		40	144	48	54.26
		143	264	24	54.26
		62	396	12	54.42
		26	96	36	54.42
		90	216	36	54.58
		29	96	24	54.58
		40	120	24	54.58
		29	96	24	54.58
		21	72	24	54.58
		17	48	24	54.58
		76	180	24	54.74
		40	144	48	54.74
		31	120	60	54.74
		152	168	24	54.90
		21	72	24	55.06
		31	120	48	55.22

APPENDIX II - continued:

Reach	Rc (m)	L (m)	Amp (m)	Distance downstream from Big Lake (km)
E	43	168	72	62.30
	33	132	72	62.46
	81	168	24	62.46
	57	120	12	62.62
	19	72	24	62.62
	95	180	24	62.78
	31	108	24	62.94
	36	144	48	62.94
	38	132	24	63.10
	40	120	24	63.27
	38	120	24	63.27
	57	156	24	63.43
	24	96	36	63.43
	62	168	36	63.59
	43	156	48	63.75
	86	300	96	63.91
	71	168	24	64.07
	38	144	72	64.07
	133	300	36	64.23
	38	144	72	64.39
	152	468	96	64.71
	71	252	60	65.04
	71	180	36	65.20
	133	288	36	65.36
	90	204	24	65.52
	105	264	48	65.68
	190	360	48	65.68
F	48	180	48	72.28
	124	288	48	72.44
	67	180	48	72.76
	38	144	48	72.92
	210	432	60	73.08
	67	204	48	73.24
	21	72	36	73.24
	38	132	48	73.24
	143	204	24	73.40
	457	456	36	73.72
	33	120	48	73.89
	38	144	48	74.05
	171	348	60	74.21
	50	180	60	74.37
	305	552	72	74.53
	52	144	24	74.69
	38	144	36	74.85
	50	168	36	75.01
	110	84	12	75.17
	229	168	12	75.17
	143	192	24	75.33
	36	132	24	75.49
	52	168	36	75.66
	210	240	12	75.82
	100	240	36	75.98

↑ small meanders

APPENDIX III

Sediment Size Data from Laboratory Analyses of the Sturgeon River bed and bank samples. Sediment sizes finer than 0.063 mm are interpolated from the cumulative frequency grain size curve. The extrapolated values finer than 0.001 mm are not included here. The first letter of the sample name is the sample cross-section location. These locations are shown on the reach maps. The number in the sample name is the collection number and the final letter in the sample name indicates whether the sample is from the right bank, "R", the left bank, "L", or the channel bed, "B".

REACH A:

Sediment Diameter (mm)	CUMULATIVE PERCENT FREQUENCY COARSER THAN Sample Number												
	A1B	A2R	A3L	B1B	B3L	C1B	C2R	C3L	D1B	D2R	D3L	D4L	E1B
20				0.00		0.00							
10				32.67		7.43							
8				38.35		11.48	0.00						
5				43.72		14.12	0.30						0.00
2.0				54.25		20.52	1.92	0.00		0.00	0.00	0.00	0.08
1.0	0.00	0.00	0.00	56.22		21.34	2.03	1.60		0.09	1.64	1.10	0.52
0.50	0.00	0.02	0.08	61.01		25.48	2.52	2.16		0.27	2.98	1.66	2.81
0.25	0.46	0.10	0.31	72.86		48.53	3.56	2.88		0.64	7.42	3.02	16.03
0.125	9.82	4.67	1.42	81.51		58.33	8.50	6.90		2.31	16.36	13.98	44.23
0.063	30.58	37.29	9.70	84.36	12.50	58.45	28.21	15.34	7.98	18.56	25.84	29.54	60.00
0.035	51	59	26	85	23	63	47	25	23	34	35	41	73
0.020	68	77	40	88	38	67	60	35	37	46	41	53	81
0.012	78	86	49	90	49	69	68	47	48	54	46	59	82
0.006	83	90	59	92	58	76	74	58	61	61	53	65	85
0.0035	85	91	64	93	65	78	77	64	66	67	59	68	86
0.0020	87	92	68	94	69	81	80	69	70	71	64	74	88

	E2R	E3L	F1B	F2R	F3L	G1B	G2R	G3L	H2R	H3L	I1B	I2R	I3L	J1B
20										0.00				
10										2.91				
8						0.00				2.91		0.00	0.00	
5						1.48	0.00		0.00	3.48	0.00	2.64	0.39	
2.0		0.00				4.65	0.28		0.13	4.61	0.10	6.07	1.17	0.00
1.0		3.50	0.00			5.58	0.52		0.34	5.15	0.39	6.79	1.53	1.14
0.5		4.36	0.30	0.00		6.71	0.86		0.75	6.23	1.16	7.68	1.95	1.98
0.25		5.38	0.78	3.66		9.75	1.73		2.32	10.50	3.80	10.71	2.66	3.20
0.125		9.14	3.62	7.36		20.53	4.39		7.99	23.37	16.74	13.70	9.22	7.66
0.063	8.46	19.18	14.96	14.94	17.67	36.03	13.09	10.92	14.26	37.00	30.57	17.19	31.19	13.54
0.035	11	29	25	24	35	42	38	16	24	40	38	23	39	19
0.020	26	41	37	34	46	47	57	24	33	47	42	27	46	23
0.012	39	49	46	42	51	54	68	32	41	53	46	31	51	27
0.006	52	57	57	52	57	63	75	44	51	60	52	37	57	34
0.0035	59	62	62	58	61	68	78	52	56	64	59	43	61	43
0.0020	65	65	67	65	64	73	81	59	61	67	64	49	65	51

REACH B:

CUMULATIVE PERCENT FREQUENCY COARSER THAN

Sediment Diameter (mm)	A1R	A3B	A4L	B1R	B3B	B4L	C1R	C3B	C4L	D1R	D3B	D4L	E1R
10					0.00								
5		0.00			0.58								
2.0		5.11			0.85			0.00			0.00		
1.0	0.00	7.39			1.28	0.00		0.46			0.16		
0.5	4.63	10.89			2.72	2.46		2.14			1.12	0.00	
0.25	5.71	20.96			7.98	3.26		12.40			5.88	0.16	
0.125	8.66	36.37			24.91	5.02		48.74			22.22	2.12	
0.063	14.49	42.47	5.60	2.00	31.16	11.22	8.00	55.46	10.42	5.72	26.82	20.90	6.90
0.035	21	46	14	4	35	22	17	58	18	10	33	36	12
0.020	30	49	25	5	39	35	28	60	30	21	35	45	17
0.012	36	52	35	11	42	44	37	62	37	32	38	51	23
0.006	41	57	43	30	47	51	47	65	47	41	42	58	29
0.0035	45	61	46	47	51	58	53	67	55	48	46	59	36
0.0020	53	65	50	61	56	64	58	71	61	55	52	62	44

Sediment Diameter (mm)	E3B	E4L	F1R	F3B	F4L	G1R	G3B	G4L	H1R	H3B	H4L	I1R	I3B
2.0	0.00			0.00			0.00			0.00			
1.0	0.14			0.21			0.04			0.12		0.00	
0.5	0.74			0.70			0.20			0.54		0.33	
0.25	3.22			4.02			1.08			2.26		1.30	
0.125	9.92			26.32			5.28			18.86		4.77	
0.063	17.60	5.74	1.94	37.52	11.90	2.16	13.92	2.68	12.10	37.20	2.60	6.88	3.98
0.035	27	15	8	42	21	7	21	13	19	40	9	13	7
0.020	33	21	11	47	32	10	26	22	29	45	13	19	18
0.012	39	27	19	50	40	16	31	31	37	47	17	22	24
0.006	42	33	26	55	48	22	39	42	45	52	21	25	37
0.0035	47	41	31	58	52	30	45	49	50	55	26	32	46
0.0020	53	48	39	61	57	40	51	55	56	60	37	38	56

REACH B, continued:

CUMULATIVE PERCENT FREQUENCY COARSER THAN

Sample Name

Sediment Diameter (mm)	I4B	I6B	I11R	I13B	I14L	J1R	J3B	J4L
10				0.00				
5				0.34				
2.0	0.00			0.59			0.00	
1.0	0.46			1.21			0.45	0.00
0.5	1.36			4.49			1.34	0.12
0.25	3.94			10.80			3.97	0.92
0.125	12.72			23.69			7.27	4.32
0.063	23.26	4.05	5.41	27.53	12.24	9.14	9.24	8.90
0.035	31	14	11	31	17	14	13	15
0.020	36	19	17	36	28	21	15	20
0.012	41	24	22	39	34	27	16	23
0.006	47	31	29	43	42	35	20	28
0.0035	51	36	35	49	48	41	25	32
0.0020	56	42	42	54	54	47	32	38

REACH C:

	AA1L	AA2B	AA4R	A1L	A3B	A4R	B1R	B2L	B3B	C1R	C2L	C3B	D1R
5	0.00						0.00					0.00	
2.0	0.14						0.58					0.30	
1.0	0.78				0.00		0.80		0.00			0.78	
0.5	1.54				0.56		1.29		0.68			1.44	
0.25	2.51				3.80		2.65		5.36			3.98	
0.125	10.08				23.84		6.21		20.08			20.76	
0.063	13.69	7.54	6.94	10.26	29.54	2.50	10.09	8.52	23.70	7.84	4.20	31.22	11.48
0.035	18	12	11	23	34	13	16	15	28	14	9	40	15
0.020	21	15	17	21	37	20	25	20	31	22	17	43	24
0.012	26	20	25	28	39	26	35	27	34	32	24	47	32
0.006	33	24	38	36	44	33	48	36	38	43	32	52	43
0.0035	37	29	42	44	48	40	54	41	43	50	40	57	51
0.0020	39	36	51	50	52	47	60	49	48	57	49	61	57

BEACH C, continued:

CUMULATIVE PERCENT FREQUENCY COARSER THAN

Sediment Diameter (mm)	D2L	D4B	E1R	E2L	E3B	F2L	F3B	G1R	G2L	G3B	H1R	H2L	H3B
20							0.00						
10							5.77						
5							10.12						0.00
2.0		0.00			0.00		13.73						0.08
1.0	0.00	0.25			0.33		14.66	0.00		0.00	0.00		0.63
0.5	0.48	1.21			0.52		16.90	1.29		0.48	0.90		2.61
0.25	1.05	2.16			1.42		23.28	1.79		3.79	1.40		12.38
0.125	1.80	5.02			5.72		30.52	3.02		18.88	5.34		17.50
0.063	2.63	9.09	12.14	4.62	10.68	8.58	35.12	6.75	7.22	24.71	15.63	6.10	20.25
0.035	13	20	14	13	18	17	47	17	12	31	29	35	34
0.020	34	31	22	19	23	28	60	30	24	37	43	57	48
0.012	58	45	30	28	26	37	65	34	32	41	52	68	56
0.006	67	57	61	35	35	46	70	45	42	46	59	75	62
0.0035	75	64	47	40	40	51	73	50	47	50	63	79	66
0.0020	77	69	56	47	47	56	76	55	55	55	69	81	70

	I3L	I8R	I11B	J3L	J6B	J7R	K3R	K4L	K5B	L1R	L2R	L3L	M1R
8											0.00		
5			0.00								0.46		
2.0			1.54		0.00	0.00			0.00	0.00	0.60		
1.0		0.00	3.87	0.00	1.73	1.58			0.16	0.07	0.76	0.00	0.00
0.5		0.90	7.98	0.42	5.64	2.20			0.92	0.15	1.56	0.93	0.52
0.25		1.56	20.67	1.09	12.56	3.48		0.00	5.44	0.97	3.44	2.05	1.26
0.125		3.83	34.37	3.32	20.62	10.32		2.42	17.24	17.54	7.67	11.97	7.94
0.063	8.62	9.77	39.47	8.90	27.26	14.40	15.72	8.67	21.78	46.46	14.95	19.32	29.54
0.035	26	19	47	26	33	20	25	44	32	56	21	31	50
0.020	44	35	54	42	41	28	39	59	42	61	25	41	63
0.012	55	46	59	50	46	34	47	67	48	63	27	47	69
0.006	61	55	64	57	52	43	54	71	55	66	31	53	72
0.0035	65	60	67	61	57	49	59	75	61	68	34	57	75
0.0020	69	66	71	65	62	54	65	77	65	71	40	61	77

REACH C, continued:

Sediment Diameter (mm)	CUMULATIVE PERCENT FREQUENCY COARSER THAN Sample Name M2L	M3B	N1R	N2L	N3L	N4B	O1R	O2L	O3B	P1R	P2L	P3B
20								0.00				
10								0.69				
8								0.69				
5				0.00	0.00	0.00		1.31				
2.0		0.00		0.18	1.03	0.19		2.64	0.00			0.00
1.0		0.62	0.00	0.99	2.67	1.82		3.53	0.23			0.11
0.5		1.86	1.06	3.19	7.34	6.63		4.96	0.76		0.00	3.78
0.25		7.70	1.76	10.53	19.53	19.68		6.92	4.30		2.10	10.86
0.125		18.14	3.74	25.40	34.41	36.28		9.58	12.74		5.00	19.66
0.063	10.84	22.42	14.54	33.85	44.21	41.16	9.26	17.78	25.50	14.27	11.86	32.46
0.035	28	28	35	43	51	48	24	27	46	33	34	44
0.020	44	34	51	50	60	52	44	41	52	55	49	52
0.012	50	39	59	55	67	55	56	49	54	65	57	57
0.006	58	45	65	63	71	59	64	56	57	71	63	61
0.0035	62	49	68	66	75	61	69	61	60	74	66	65
0.0020	66	54	71	71	79	64	72	65	63	77	70	68

REACH D:

CUMULATIVE PERCENT FREQUENCY COARSER THAN

Sediment Diameter (mm)	A1B	A2R	A3L	Sample Name B1B	B2R	B3L	C1B	C2R	C3L
5				0.00			0.00		
4.0				0.01			0.13		
2.83				0.02			0.16		
2.00		0.00	0.00	0.03	0.00	0.00	0.26	0.00	0.00
1.41		0.29	0.05	0.04	0.02	0.07	0.31	0.12	0.21
1.00	0.00	1.00	0.14	0.16	0.07	0.17	0.50	0.31	0.35
0.71	0.10	0.51	0.30	0.38	0.16	0.25	1.54	0.56	0.55
0.500	0.34	0.65	0.52	0.74	0.29	0.38	7.56	0.90	0.77
0.354	1.67	0.90	0.89	2.47	1.21	0.73	44.17	1.59	1.22
0.250	5.50	1.39	1.56	7.92	5.03	6.07	72.85	4.99	5.98
0.177	15.00	5.19	8.22	16.27	10.78	27.43	85.32	17.47	22.49
0.125	30.36	17.25	23.74	28.18	23.46	49.93	89.33	29.21	41.63
0.088	41.40	31.28	40.44	35.28	33.24	64.50	91.27	37.84	53.63
0.063	47.01	40.62	51.32	40.34	40.46	71.66	92.14	42.76	59.99
0.035	57	58	70	51	59	81	95	52	67
0.020	66	68	85	61	69	87	96	61	73
0.012	74	74	81	68	76	89	97	69	77
0.006	79	80	85	73	83	91	97	74	81
0.0035	81	84	87	77	85	92	97	77	83
0.0020	84	87	89	79	87	93	98	80	85

/	D1B	D2R	D3L	D4B	E1B	E2R	E3L	F1B	F2R
20								0.00	
10								0.52	
8.0								0.73	
5.0								0.73	
4.00								1.14	
2.83					0.00			1.14	
2.00	0.00			0.00	0.83	0.00		1.15	0.00
1.41	0.11	0.00	0.00	0.06	0.05	0.29		1.18	0.01
1.00	0.30	0.05	0.04	0.15	0.19	0.42	0.00	1.38	0.14
0.71	0.47	0.07	0.10	0.27	0.78	0.52	0.05	2.61	0.94
0.500	0.70	0.12	0.20	0.41	5.76	0.68	0.08	8.65	4.95
0.354	2.02	1.11	0.75	2.28	40.25	1.10	0.18	40.19	21.75
0.250	13.26	9.21	5.63	13.84	82.05	2.32	1.90	76.18	45.47
0.177	33.49	43.29	24.27	33.70	94.73	8.15	18.51	90.57	60.84
0.125	46.07	66.17	48.72	45.21	96.72	22.71	48.53	92.96	72.07
0.088	53.18	76.66	63.53	51.79	97.30	37.54	67.61	93.90	80.10
0.063	56.77	81.0[illegible]	70.31	55.38	97.50	47.01	74.79	94.36	83.55
0.035	65	86	79	63	99	59	87	95	90
0.020	71	90	85	69	99	69	90	95	92
0.012	75	92	88	74	99	73	92	96	93
0.006	80	93	90	78	99	77	94	97	95
0.0035	82	94	91	81	99	81	95	97	95
0.0020	84	95	92	83	100	83	95	98	95

REACH D, continued:

CUMULATIVE PERCENT FREQUENCY COARSER THAN

Sample Name

Sediment Diameter (mm)	F3L	G1B	G2R	G3L	H1B	H2R	H3L	I1B	I2R
5.0		0.00		0.00	0.00				
4.00		0.11		0.31	0.17				
2.83		0.32		0.47	0.48				
2.00		0.48		0.77	0.73	0.00	0.00		0.00
1.41	0.00	0.64	0.00	1.01	1.65	0.05	0.48	0.00	0.22
1.00	0.02	0.87	0.10	1.61	2.23	0.14	0.68	0,01	0.40
0.71	0.05	1.24	0.22	2.44	3.76	0.28	0.85	0.35	0.58
0.500	0.13	2.06	0.36	3.81	8.97	0.53	1.04	3.44	0.83
0.354	0.74	6.09	0.64	7.08	33.27	0.91	1.38	20.86	1.19
0.250	11.48	36.60	2.19	11.02	68.82	3.55	2.27	49.98	2.51
0.177	66.26	79.97	25.63	16.44	84.34	15.05	9.32	74.78	10.82
0.125	90.22	85.27	56.15	21.65	88.56	34.86	28.87	80.41	37.93
0.088	94.89	86.79	69.97	26.92	90.14	45.14	44.74	82.45	42.94
0.063	95.79	87.68	75.23	30.37	90.83	51.90	52.39	83.43	49.49
0.035	98	90	84	39	94	63	64	88	64
0.020	98	91	88	49	95	74	70	89	74
0.012	99	92	89	55	96	79	75	91	78
0.006	99	92	92	65	96	83	79	93	82
0.0035	99	94	93	71	96	86	82	94	86
0.0020	99	95	94	76	96	89	83	95	89

	I3L	J1B	J2R	J3L	K1B	K2R	K3L	L1B	L2R
8.0								0.00	
5.0								0.66	
4.00								1.13	
2.83	0.00							1.13	
2.00	0.09				0.00			1.52	0.00
1.41	0.14		0.00		0.20	0.00		1.69	0.02
1.00	0.35	0.00	0.17	0.00	0.27	0.10		1.97	0.02
0.71	0.69	0.05	0.30	0.27	0.68	0.15	0.00	2.93	0.04
0.500	1.81	0.12	0.48	0.47	2.61	0.27	0.05	8.36	0.21
0.354	10.34	6.15	0.78	0.75	19.73	2.92	0.76	44.60	6.90
0.250	35.83	47.05	2.22	2.43	57.60	18.76	4.22	69.31	44.08
0.177	62.05	84.94	14.74	11.23	79.32	45.23	19.26	73.30	85.00
0.125	76.34	90.72	36.07	24.02	85.05	61.37	39.60	75.43	94.52
0.088	81.91	92.13	51.28	33.81	87.22	71.34	54.67	77.85	96.52
0.063	84.37	92.64	60.12	40.76	88.12	76.00	62.82	79.49	96.99
0.035	89	94	72	53	91	85	76	83	99
0.020	92	96	79	64	92	88	81	86	99
0.012	93	97	82	71	93	90	85	89	99
0.006	94	97	86	77	94	91	87	91	100
0.0035	95	97	88	80	95	92	89	93	
0.0020	97	97	89	83	97	94	90	93	

REACH D, continued:

Sediment Diameter (mm)	CUMULATIVE PERCENT FREQUENCY COARSER THAN Sample Name L3L	M1B	M2R	M3L	N1B	N2R	N3L	O1B	O2R
5.0								0.00	
4.00					0.00			0.67	
2.83		0.00			0.29			1.65	
2.00	0.00	0.47			0.44			2.39	0.00
1.41	0.03	0.72			0.44	0.00		2.51	0.10
1.00	0.11	0.81	0.00	0.00	0.60	0.05	0.00	2.78	0.24
0.71	0.21	0.92	0.13	0.03	1.27	0.13	0.18	3.34	0.41
0.500	0.36	1.37	0.52	0.09	4.03	0.50	0.22	5.39	1.21
0.354	0.62	30.22	7.88	0.72	18.28	4.68	0.29	18.97	15.09
0.250	2.62	63.56	28.57	10.87	65.90	16.91	0.86	42.55	45.63
0.177	25.44	86.89	54.00	45.32	85.71	39.38	10.54	53.39	71.58
0.125	58.57	91.38	65.93	68.47	89.56	55.46	32.96	59.76	78.89
0.088	74.67	92.68	73.10	77.47	91.29	63.95	46.49	64.82	82.19
0.063	78.79	93.09	75.96	80.62	92.06	68.45	53.68	67.99	83.49
0.035	87	95	84	87	94	74	63	74	87
0.020	89	95	88	89	96	80	74	78	89
0.012	91	95	91	91	97	84	79	81	91
0.006	93	96	93	93	97	88	84	83	94
0.0035	95	97	95	93	97	89	86	84	95
0.0020	95	98	95	94	98	91	87	85	96

	O3L	P1B	P2R	P3L
5.0			0.00	
4.00			0.31	
2.83			0.43	
2.00			0.64	
1.41	0.00	0.00	0.74	0.00
1.00	0.08	0.08	1.10	0.25
0.71	0.22	0.29	2.64	0.45
0.500	0.79	1.89	9.67	0.70
0.354	12.93	14.77	49.47	2.09
0.250	50.11	38.96	83.66	12.79
0.177	70.98	60.34	92.99	32.54
0.125	76.73	67.48	94.09	44.52
0.088	80.21	70.63	94.52	51.39
0.063	82.11	72.63	94.72	55.79
0.035	88	79	96	64
0.020	91	84	96	71
0.012	93	87	97	75
0.006	95	89	97	81
0.0035	95	91	98	82
0.0020	95	93	99	84

REACH E:

CUMULATIVE-PERCENT FREQUENCY COARSER THAN

Sediment Diameter (mm)	Sample Name A1R	A4L	B1R	B3L	C1R	C4L	D1R	D4L	E1R
2.00	0.00	0.00	0.00			0.00	0.00		
1.41	0.07	0.04	0.09	0.00	0.00	0.18	0.67	0.00	0.00
1.00	0.19	0.28	0.18	0.75	0.18	0.36	0.92	0.16	0.58
0.71	0.36	0.99	0.30	1.06	0.29	0.59	1.10	0.22	0.74
0.500	0.70	2.09	0.48	1.39	0.40	0.86	1.31	0.30	0.96
0.354	2.83	3.26	1.90	1.93	0.96	1.44	1.74	0.47	1.34
0.250	11.58	4.48	10.40	3.14	4.21	2.93	3.40	3.12	2.94
0.177	34.53	7.97	34.95	8.36	15.14	8.59	8.61	17.48	12.34
0.125	50.95	13.67	55.36	18.77	29.56	16.87	18.25	33.49	29.56
0.088	61.48	24.60	69.91	35.98	41.36	27.59	30.54	48.78	42.22
0.063	67.35	36.05	77.22	50.11	49.40	36.85	41.80	58.48	49.48
0.035	77	50	87	68	62	57	59	73	63
0.020	83	59	89	79	67	69	74	81	72
0.012	85	62	91	84	71	76	80	85	77
0.006	88	66	92	86	75	80	83	87	81
0.0035	89	70	93	87	77	82	85	88	83
0.0020	90	74	94	88	78	85	87	89	85

	E4L	F1R	F4L	G2R	G4L	H1R	H4L	I1R	I4L
8.0						0.00			
5.0				0.00		0.84		0.00	
4.00				2.42	0.00	2.74		0.52	
2.83			0.00	2.95	0.03	3.86		0.69	
2.00	0.00		0.89	3.01	0.10	4.98		0.76	0.00
1.41	0.42	0.00	1.39	3.04	0.68	5.53	0.00	1.05	0.19
1.00	0.59	0.45	1.56	3.22	1.01	6.11	0.05	1.39	0.43
0.71	0.78	0.61	1.75	3.46	1.55	6.64	0.07	1.90	0.62
0.500	1.03	0.81	2.00	3.75	3.39	7.22	0.13	2.56	0.82
0.354	1.45	1.29	2.59	4.36	11.56	8.56	0.98	3.83	5.07
0.250	2.02	2.91	4.67	6.60	19.58	12.44	13.09	7.60	22.36
0.177	5.90	8.91	14.58	12.69	29.10	21.13	36.75	22.60	48.82
0.125	17.03	19.88	31.44	19.24	40.26	30.72	58.50	44.57	63.74
0.088	32.23	30.32	44.96	25.48	50.20	39.43	72.57	59.22	72.90
0.063	43.68	37.98	54.63	30.33	56.62	45.72	78.81	67.07	78.95
0.035	61	54	69	41	68	58	88	78	87
0.020	74	65	79	49	75	67	91	84	91
0.012	80	71	83	55	79	73	93	87	93
0.006	83	75	85	61	83	76	94	89	94
0.0035	85	78	87	66	85	80	95	90	94
0.0020	87	81	88	70	87	83	95	91	95

REACH E, continued:

Sediment Diameter (mm)	CUMULATIVE PERCENT FREQUENCY COARSER THAN Sample Name			
	I5L	J1R	K1R	K4L
20		0.00		
10		22.54		
8.0		23.93		
5.0	0.00	24.45		0.00
4.00	0.31	25.18		0.15
2.83	0.59	25.39		0.21
2.00	0.85	25.55	0.00	0.27
1.41	0.87	25.81	0.20	0.44
1.00	0.88	25.94	0.28	0.57
0.71	0.89	26.11	0.40	0.73
0.500	0.92	26.38	0.53	1.00
0.354	3.21	26.99	0.96	1.47
0.250	15.05	28.21	2.62	4.28
0.177	39.56	34.79	8.41	25.58
0.125	51.43	44.88	14.65	51.34
0.088	55.07	53.14	21.60	65.70
0.063	59.64	60.03	28.07	71.74
0.035	62	72	40	81
0.020	67	79	49	85
0.012	69	82	55	87
0.006	73	85	63	89
0.0035	75	87	66	90
0.0020	80	89	70	91
	AAB	FB	JB	LB
431				0.00
304	0.00	0.00		1.67
215	3.08	1.67		5.00
152	13.85	1.67		6.67
108	35.35	11.67	0.00	15.00
76	47.70	25.00	6.67	23.34
54	58.47	45.00	18.34	38.34
38	64.62	61.67	41.67	65.01
27	73.85	75.00	66.67	78.34
19	80.00	76.67	83.33	91.67
13	84.62	95.00	98.33	100.00
9.5	90.77	98.33	100.00	
6.7	92.31	100.00		
4.8	96.92			
3.4	96.92			
2.4	100.00			

REACH F:

CUMULATIVE PERCENT FREQUENCY COARSER THAN

Sample Name

Sediment Diameter (mm)	A1L	B1L	B2R	C1L	C2R	D1L	DD1L	DDD1L	DDD2R
4.00									0.00
2.83									0.08
2.00							0.00	0.00	0.11
1.41		0.00				0.00	0.05	0.32	0.16
1.00	0.00	0.08	0.00	0.00		0.02	0.11	0.58	0.19
0.71	0.11	0.17	0.21	0.30	0.00	0.07	0.20	0.82	0.27
0.500	0.19	0.19	0.39	0.47	1.03	0.22	0.31	1.08	0.31
0.354	0.64	1.29	0.94	0.80	2.03	4.15	0.57	1.32	0.73
0.250	5.93	7.72	5.43	2.30	3.38	21.47	2.13	4.07	2.47
0.177	36.46	19.23	27.99	8.08	11.52	53.35	15.96	14.41	14.02
0.125	64.37	29.90	58.15	17.21	29.91	69.61	41.04	27.91	33.40
0.088	76.65	39.00	73.31	25.61	42.69	76.45	59.05	41.03	50.04
0.063	81.76	48.39	79.59	39.41	60.23	79.54	69.07	51.85	61.17
0.035	87	61	84	57	72	87	80	70	75
0.020	89	69	87	71	79	90	85	86	82
0.012	91	75	88	77	83	92	88	81	86
0.006	92	89	89	81	87	94	91	84	89
0.0035	92	92	90	83	87	94	92	87	90
0.0020	93	94	91	85	88	95	92	89	91

	DDDD1L	DDDD2R	E1L	E2R	F1L	F2R	G1L	G2R	H1L
4.00	0.00								
2.83	0.04								
2.00	0.04	0.00					0.00		
1.41	0.04	0.26					0.44		
1.00	0.04	0.38	0.00	0.00			0.76	0.00	0.00
0.71	0.63	0.53	0.20	0.11	0.00		0.92	0.36	0.11
0.500	0.89	0.74	0.38	0.18	1.29	0.00	1.08	0.63	0.24
0.354	2.88	1.24	1.68	1.72	1.55	1.01	1.25	1.23	0.74
0.250	13.56	3.01	11.66	23.78	2.51	2.47	1.60	6.04	3.54
0.177	30.30	11.48	36.27	42.78	7.43	6.84	4.17	21.21	20.16
0.125	44.17	26.33	56.31	48.41	16.22	14.08	16.28	39.17	43.50
0.088	54.98	41.81	67.87	51.92	24.94	23.40	32.67	51.18	60.37
0.063	62.58	54.70	74.24	53.08	37.53	32.46	45.55	62.61	68.89
0.035	75	71	80	57	53	52	65	86	79
0.020	81	81	84	63	69	68	76	83	84
0.012	84	85	86	67	75	76	81	86	87
0.006	87	88	89	73	79	81	85	87	88
0.0035	89	89	90	76	82	83	87	89	89
0.0020	90	91	91	80	84	85	87	91	91

REACH F, continued:

Sediment Diameter (mm)	CUMULATIVE PERCENT FREQUENCY COARSER THAN Sample Name H2R	I1L	I2R	J1L	J2R	K1L	K2R	L1L	L2R
2.00	0.00					0.00			
1.41	0.45			0.00		0.02			
1.00	0.80		0.00	0.11	0.00	0.04			0.00
0.71	1.15	0.00	0.67	0.27	0.03	0.06	0.00	0.00	0.06
0.500	1.56	0.43	0.85	0.51	0.08	0.14	0.22	0.07	0.09
0.354	2.72	0.65	1.24	2.83	0.38	0.31	0.44	0.72	0.76
0.250	7.27	1.95	4.37	13.94	0.60	3.88	1.07	11.75	2.94
0.177	22.29	8.33	19.21	34.72	1.38	23.74	4.11	63.90	10.04
0.125	38.79	18.71	37.31	51.15	3.38	44.54	12.05	83.58	21.25
0.088	51.25	29.70	53.68	63.37	7.03	61.00	21.60	90.42	31.62
0.063	59.50	44.22	64.47	71.49	14.91	71.02	46.06	93.86	40.29
0.035	73	64	75	83	27	83	62	95	54
0.020	81	75	83	88	46	87	75	96	66
0.012	85	80	87	90	43	90	80	97	74
0.006	87	83	89	92	50	92	84	97	79
0.0035	89	85	91	93	55	93	85	97	81
0.0020	90	87	91	94	62	93	87	97	84

	M1L	M2R	N1L	N3R
5.0			0.00	
4.00			0.25	
2.83			0.46	
2.00		0.00	0.67	0.00
1.41		0.01	0.81	0.40
1.00	0.00	0.02	1.09	0.75
0.71	0.25	0.05	1.82	1.20
0.500	0.38	0.13	4.14	1.83
0.354	0.92	0.52	12.59	3.25
0.250	2.92	8.63	25.68	9.49
0.177	11.32	24.16	42.42	27.43
0.125	27.20	37.33	56.43	39.33
0.088	44.09	50.45	65.14	48.97
0.063	57.43	57.46	71.16	56.54
0.035	73	67	79	66
0.020	81	76	84	73
0.012	85	81	87	78
0.006	88	84	89	82
0.0023	89	86	90	84
0.0020	90	87	91	87

REACH F, continued:

Sediment Diameter (mm)	CUMULATIVE PERCENT FREQUENCY COARSER THAN Sample Name				
	A2R	C3B	DDDB	N2L	N4B
861		0.00			
609		3.33	0.00		
431		5.00	3.33		
304		10.00	3.33		
215		10.00	11.66		
152		15.00	18.33		
108		23.33	25.00		
76		36.66	28.33	0.00	0.00
54	0.00	54.95	40.00	8.33	18.33
38	1.70	66.66	53.33	21.66	40.00
27	13.56	83.33	70.00	39.95	65.00
19	35.59	93.33	86.67	48.32	90.00
13	59.32	98.33	94.95	61.66	95.00
9.5	74.57	100.00	96.66	71.66	95.00
6.7	94.91		98.33	84.95	98.33
4.8	100.00		100.00	91.66	100.00
3.4				96.66	
2.4				98.33	
1.7				98.33	
1.2				100.00	

APPENDIX IV - Detailed regression analysis results for the Sturgeon River data sets

App.IVa. Channel width to depth ratios, W/Dx and W/Dm, for the observed, o, and first-break-in-slope, fb, water levels regressed on the channel perimeter sediment variables for the Sturgeon River reaches.

Ref. No.	Data set	Relation	Exponent	Student's t of exponent	Two-tailed significance of t (%)	Coefficient of determination, r^2	Sample size
1	Reach A	(W/Dx)o = f(%CBK)	0.57	0.57	<50	0.03	11
2		(W/Dm)o = f(%CBK)	0.56	0.50	<50	0.03	11
3		(W/Dx)o = f(%CBD)	0.17	0.50	<50	0.03	11
4		(W/Dm)o = f(%CBD)	0.19	0.48	<50	0.02	11
5		(W/Dx)o = f(%SCBK)	-9.70	-4.05	99	0.65	11
6		(W/Dm)o = f(%SCBK)	-10.63	-3.81	99	0.62	11
7		(W/Dx)o = f(%SCBD)	-0.30	-0.43	<50	0.02	11
8		(W/Dm)o = f(%SCBD)	-0.31	-0.41	<50	0.02	11
9		(W/Dx)o = f(Mo)	-0.43	-0.57	<50	0.03	11
10		(W/Dm)o = f(Mo)	-0.46	-0.54	<50	0.03	11
11		(W/Dx)o = f(MBK)	-0.25	-0.45	<50	0.02	11
12		(W/Dm)o = f(MBK)	-0.26	-0.42	<50	0.02	11
13		(W/Dx)o = f(MBD)	-0.01	-0.06	<50	0.0004	11
14		(W/Dm)o = f(MBD)	-0.01	-0.06	<50	0.0004	11
15		(W/Dx) fb = f(%CBK)	0.37	0.39	<50	0.02	11
16		(W/Dm) fb = f(%CBK)	0.38	0.31	<50	0.01	11
17		(W/Dx) fb = f(%CBD)	0.08	0.24	<50	0.006	11
18		(W/Dm) fb = f(%CBD)	0.14	0.34	<50	0.01	11
19		(W/Dx) fb = f(%SCBK)	-7.40	-2.55	95	0.42	11
20		(W/Dm) fb = f(%SCBK)	-10.91	-3.46	99	0.57	11
21		(W/Dx) fb = f(%SCBD)	-0.35	-0.52	<50	0.03	11
22		(W/Dm) fb = f(%SCBD)	-0.35	-0.42	<50	0.02	11
23		(W/Dx) fb = f(Mfb)	-0.80	-1.88	90	0.31	10
24		(W/Dm) fb = f(Mfb)	-0.89	-1.46	80	0.21	10
25		(W/Dx) fb = f(MBK)	-0.18	-0.36	<50	0.01	11
26		(W/Dm) fb = f(MBK)	-0.14	-0.21	<50	0.005	11
27		(W/Dx) fb = f(MBD)	0.02	0.16	<50	0.003	11
28		(W/Dm) fb = f(MBD)	0.005	0.03	<50	0.0001	11
29	Reach B	(W/Dx)o = f(%CBK)	-0.29	-0.67	<50	0.08	7
30		(W/Dm)o = f(%CBK)	-0.01	-0.03	<50	0.0002	7
31		(W/Dx)o = f(%CBD)	0.02	0.03	<50	0.0001	7
32		(W/Dm)o = f(%CBD)	0.36	0.64	<50	0.38	7
33		(W/Dx)o = f(%SCBK)	-13.40	-2.88	95	0.62	7
34		(W/Dm)o = f(%SCBK)	-11.41	-2.45	90	0.55	7
35		(W/Dx)o = f(%SCBD)	-0.07	-0.13	<50	0.003	7
36		(W/Dm)o = f(%SCBD)	0.24	0.47	<50	0.04	7
37		(W/Dx)o = f(Mo)	-0.22	-0.31	<50	0.02	7
38		(W/Dm)o = f(Mo)	0.20	0.30	<50	0.02	7
39		(W/Dx)o = f(MBK)	0.09	0.57	<50	0.06	7
40		(W/Dm)o = f(MBK)	-0.01	-0.10	<50	0.002	7
41		(W/Dx)o = f(MBD)	-0.06	-0.36	<50	0.02	7
42		(W/Dm)o = f(MBD)	-0.14	-1.05	50	0.18	7
43		(W/Dx) fb = f(%CBK)	0.05	0.06	<50	0.002	4

App. IVa. continued:

Ref. No.	Data set	Relation	Exponent	Student's t of exponent	Two-tailed significance of t (%)	Coefficient of determination, r^2	Sample size
44	Reach B	(W/Dm) fb = f(%CBK)	0.19	0.25	<50	0.30	4
45		(W/Dx) fb = f(%CBD)	-0.04	-0.05	<50	0.001	4
46		(W/Dm) fb = f(%CBD)	-0.01	-0.02	<50	0.001	4
47		(W/Dx) fb = f(%SCBK)	3.15	0.15	<50	0.01	4
48		(W/Dm) fb = f(%SCBK)	10.50	0.60	<50	0.14	4
49		(W/Dx) fb = f(%SCBD)	0.14	0.18	<50	0.02	4
50		(W/Dm) fb = f(%SCBD)	0.22	0.31	<50	0.05	4
51		(W/Dx) fb = f(Mfb)	0.10	0.10	<50	0.005	4
52		(W/Dm) fb = f(Mfb)	0.23	0.25	<50	0.03	4
53		(W/Dx) fb = f(MBK)	-0.03	-0.10	<50	0.005	4
54		(W/Dm) fb = f(MBK)	-0.09	-0.38	<50	0.07	4
55		(W/Dx) fb = f(MBD)	0.04	0.21	<50	0.02	4
56		(W/Dm) fb = f(MBD)	0.04	0.20	<50	0.02	4
57	Reach C	(W/Dx)o = f(%CBK)	0.78	2.12	90	0.43	8
58		(W/Dm)o = f(%CBK)	0.43	1.57	80	0.29	8
59		(W/Dx)o = f(%CBD)	0.85	1.56	80	0.29	8
60		(W/Dm)o = f(%CBD)	0.32	0.79	50	0.09	8
61		(W/Dx)o = f(%SCBK)	2.40	1.40	50	0.25	8
62		(W/Dm)o = f(%SCBK)	1.85	1.72	80	0.33	8
63		(W/Dx)o = f(%SCBD)	0.03	0.71	50	0.08	8
64		(W/Dm)o = f(%SCBD)	0.02	0.92	50	0.12	8
65		(W/Dx)o = f(Mo)	0.14	0.68	<50	0.07	8
66		(W/Dm)o = f(Mo)	0.12	0.89	50	0.12	8
67		(W/Dx)o = f(MBK)	-0.27	-2.10	90	0.42	8
68		(W/Dm)o = f(MBK)	-0.15	-1.57	80	0.29	8
69		(W/Dx)o = f(MBD)	-0.03	-0.96	50	0.13	8
70		(W/Dm)o = f(MBD)	-0.02	-1.02	50	0.15	8
71		(W/Dx) fb = f(%CBK)	1.71	3.84	95	0.83	5
72		(W/Dm) fb = f(%CBK)	1.30	3.02	90	0.75	5
73		(W/Dx) fb = f(%CBD)	2.09	3.87	95	0.83	5
74		(W/Dm) fb = f(%CBD)	1.61	3.22	95	0.78	5
75		(W/Dx) fb = f(%SCBK)	4.85	1.19	50	0.32	5
76		(W/Dm) fb = f(%SCBK)	4.08	1.29	50	0.36	5
77		(W/Dx) fb = f(%SCBD)	1.30	0.35	<50	0.04	5
78		(W/Dm) fb = f(%SCBD)	1.38	0.47	<50	0.07	5
79		(W/Dx) fb = f(Mfb)	0.63	0.15	<50	0.008	5
80		(W/Dm) fb = f(Mfb)	0.89	0.27	<50	0.02	5
81		(W/Dx) fb = f(MBK)	-0.59	-4.23	95	0.86	5
82		(W/Dm) fb = f(MBK)	-0.46	-3.45	95	0.80	5
83		(W/Dx) fb = f(MBD)	-0.50	-3.12	90	0.76	5
84		(W/Dm) fb = f(MBD)	-0.40	-3.15	90	0.77	5
85	Reach D	(W/Dx)o = f(%CBK)	0.17	0.59	<50	0.11	5
86		(W/Dm)o = f(%CBK)	0.13	0.35	<50	0.04	5

App. IVa. continued:

Ref. No.	Data set	Relation	Exponent	Student's t of exponent	Two-tailed significance of t (%)	Coefficient of determination, r^2	Sample size
87	Reach D	(W/Dx)o = f(%CBD)	-0.31	-2.00	80	0.57	5
88		(W/Dm)o = f(%CBD)	-0.41	-2.28	80	0.63	5
89		(W/Dx)o = f(%SCBK)	0.16	0.47	<50	0.07	5
90		(W/Dm)o = f(%SCBK)	0.16	0.39	<50	0.05	5
91		(W/Dx)o = f(%SCBD)	-0.40	-1.66	80	0.48	5
92		(W/Dm)o = f(%SCBD)	-0.50	-1.71	80	0.49	5
93		(W/Dx)o = f(Mo)	-0.65	-2.13	80	0.60	5
94		(W/Dm)o = f(Mo)	-0.82	-2.25	80	0.63	5
95		(W/Dx)o = f(MBK)	-0.06	-0.26	<50	0.02	5
96		(W/Dm)o = f(MBK)	-0.02	-0.07	<50	0.002	5
97		(W/Dx)o = f(MBD)	0.35	1.80	80	0.52	5
98		(W/Dm)o = f(MBD)	0.42	1.66	80	0.48	5
99		(W/Dx) fb = f(%CBK)	-0.02	-0.12	<50	0.005	5
100		(W/Dm) fb = f(%CBK)	-0.33	-1.08	50	0.28	5
101		(W/Dx) fb = f(%CBD)	-0.06	-0.39	<50	0.05	5
102		(W/Dm) fb = f(%CBD)	0.05	0.19	<50	0.01	5
103		(W/Dx) fb = f(%SCBK)	-0.03	-0.15	<50	0.007	5
104		(W/Dm) fb = f(%SCBK)	-0.35	-1.00	50	0.25	5
105		(W/Dx) fb = f(%SCBD)	-0.01	-0.04	<50	0.0005	5
106		(W/Dm) fb = f(%SCBD)	0.16	0.44	<50	0.06	5
107		(W/Dx) fb = f(Mfb)	-0.15	-0.47	<50	0.07	5
108		(W/Dm) fb = f(Mfb)	-0.10	-0.16	<50	0.07	5
109		(W/Dx) fb = f(MBK)	0.06	0.45	<50	0.06	5
110		(W/Dm) fb = f(MBK)	0.30	1.50	50	0.43	5
111		(W/Dx) fb = f(MBD)	0.03	0.18	<50	0.01	5
112		(W/Dm) fb = f(MBD)	-0.15	-0.47	<50	0.07	5
113	Reach E	(W/Dx)o = f(%CBK)	1.03	1.85	80	0.53	5
114		(W/Dm)o = f(%CBK)	1.44	1.97	80	0.56	5
115		(W/Dx)o = f(%SCBK)	-0.34	-0.44	<50	0.06	5
116		(W/Dm)o = f(%SCBK)	-0.49	-0.47	<50	0.07	5
117		(W/Dx)o = f(Mo)	-0.65	-2.61	90	0.69	5
118		(W/Dm)o = f(Mo)	-0.88	-2.63	90	0.70	5
119		(W/Dx)o = f(MBK)	-0.86	-1.15	50	0.31	5
120		(W/Dm)o = f(MBK)	-1.41	-1.57	50	0.45	5
121		(W/Dx)o = f(MBD)	0.11	0.10	<50	0.003	5
122		(W/Dm)o = f(MBD)	-0.07	-0.05	<50	0.0007	5
123		(W/Dx) fb = f(%CBK)	1.48	3.02	90	0.75	5
124		(W/Dm) fb = f(%CBK)	1.63	2.21	80	0.62	5
125		(W/Dx) fb = f(%SCBK)	-1.56	-4.89	98	0.89	5
126		(W/Dm) fb = f(%SCBK)	-1.92	-5.95	99	0.92	5
127		(W/Dx) fb = f(Mfb)	-0.69	-12.22	99.8	0.98	5
128		(W/Dm) fb = f(Mfb)	-0.82	-6.28	99	0.93	5
129		(W/Dx) fb = f(MBK)	-0.35	-0.33	<50	0.04	5
130		(W/Dm) fb = f(MBK)	0.15	0.12	<50	0.005	5

App. IVa. continued:

Ref. No.	Data set	Relation	Exponent	Student's t of exponent	Two-tailed significance of t (%)	Coefficient of determination, r^2	Sample size
131	Reach E	(W/Dx) fb = f(MBD)	-1.63	-1.76	80	0.51	5
132		(W/Dm) fb = f(MBD)	-1.78	-1.45	50	0.41	5
133	Reach F	(W/Dx)o = f(%CBK)	2.24	2.41	90	0.59	6
134		(W/Dm)o = f(%CBK)	2.26	2.22	90	0.55	6
135		(W/Dx)o = f(%SCBK)	0.86	2.31	90	0.57	6
136		(W/Dm)o = f(%SCBK)	0.74	1.60	80	0.39	6
137		(W/Dx)o = f(Mo)	-0.67	-0.93	50	0.18	6
138		(W/Dm)o = f(Mo)	-0.89	-1.25	50	0.28	6
139		(W/Dx)o = f(MBK)	-0.34	-2.12	80	0.53	6
140		(W/Dm)o = f(MBK)	-0.28	-1.39	50	0.33	6
141		(W/Dx)o = f(MBD)	0.64	0.93	50	0.18	6
142		(W/Dm)o = f(MBD)	0.28	0.35	<50	0.03	6
143		(W/Dx) fb = f(%CBK)	0.72	1.37	50	0.32	6
144		(W/Dm) fb = f(%CBK)	0.35	0.50	<50	0.06	6
145		(W/Dx) fb = f(%SCBK)	-0.08	-0.31	<50	0.02	6
146		(W/Dm) fb = f(%SCBK)	-0.07	-0.26	<50	0.02	6
147		(W/Dx) fb = f(Mfb)	-0.22	-1.16	50	0.25	6
148		(W/Dm) fb = f(Mfb)	-0.18	-0.81	50	0.14	6
149		(W/Dx) fb = f(MBK)	0.05	0.49	< 50	0.06	6
150		(W/Dm) fb = f(MBK)	0.03	0.28	< 50	0.02	6
151		(W/Dx) fb = f(MBD)	0.18	0.55	<50	0.07	6
152		(W/Dm) fb = S(MBD)	0.14	0.37	<50	0.03	6
153	Reaches A to C	(W/Dx)o = f(%CBK)	-0.40	-0.87	50	0.03	26
154		(W/Dm)o = f(%CBK)	-0.54	-1.14	50	0.05	26
155		(W/Dx)o = f(%CBD)	-0.52	-2.02	90	0.15	26
156		(W/Dm)o = f(%CBD)	-0.58	-2.19	95	0.17	26
157		(W/Dx)o = f(%SCBK)	-5.41	-3.64	99.8	0.36	26
158		(W/Dm)o = f(%SCBK)	-6.05	-4.08	99.8	0.41	26
159		(W/Dx)o = f(%SCBD)	0.06	0.97	50	0.04	26
160		(W/Dm)o = f(%SCBD)	0.06	0.87	50	0.03	26
161		(W/Dx)o = f(Mo)	-0.05	-0.15	<50	0.001	26
162		(W/Dm)o = f(Mo)	-0.07	-0.21	< 50	0.002	26
163		(W/Dx)o = f(MBK)	0.19	1.23	50	0.06	26
164		(W/Dm)o = f(MBK)	0.24	1.50	80	0.09	26
165		(W/Dx)o = f(MBD)	0.02	0.35	<50	0.005	26
166		(W/Dm)o = f(MBD)	0.03	0.53	< 50	0.01	26
167		(W/Dx) fb = f(%CBK)	-0.17	-0.50	< 50	0.01	19
168		(W/Dm) fb = f(%CBK)	-0.21	-0.60	< 50	0.02	19
169		(W/Dx) fb = f(%CBD)	-0.31	-1.73	80	0.15	19
170		(W/Dm) fb = f(%CBD)	-0.28	-1.51	80	0.12	19
171		(W/Dx) fb = f(%SCBK)	-3.36	-2.17	95	0.21	20
172		(W/Dm) fb = f(%SCBK)	-3.90	-2.39	95	0.24	20
173		(W/Dx) fb = f(%SCBD)	-0.67	-1.33	50	0.09	20
174		(W/Dm) fb = f(%SCBD)	-0.60	-1.09	50	0.07	20

App. IVa. continued:

Ref. No.	Data set	Relation	Exponent	Student's t of exponent	Two-tailed significance of t, (%)	Coefficient of determination, r^2	Sample size
175	Reaches A to C	(W/Dx)fb = f(Mfb)	-0.91	-2.25	95	0.23	19
176		(W/Dm)fb = f(Mfb)	-0.84	-1.98	90	0.19	19
177		(W/Dx)fb = f(MBK)	0.04	0.30	<50	0.005	19
178		(W/Dm)fb = f(MBK)	0.04	0.33	<50	0.006	19
179		(W/Dx)fb = f(MBD)	0.10	1.65	80	0.14	19
180		(W/Dm)fb = f(MBD)	0.09	1.45	80	0.11	19
181	Reaches E & F	(W/Dx)o = f(%CBK)	-0.07	-0.14	<50	0.002	11
182		(W/Dm)o = f(%CBK)	-0.04	-0.06	<50	0.0004	11
183		(W/Dx)o = f(%SCBK)	0.14	0.40	<50	0.02	11
184		(W/Dm)o = f(%SCBK)	0.05	0.13	<50	0.002	11
185		(W/Dx)o = f(Mo)	-0.55	-2.63	95	0.44	11
186		(W/Dm)o = f(Mo)	-0.63	-2.93	98	0.49	11
187		(W/Dx)o = f(MBK)	-0.08	-0.50	<50	0.03	11
188		(W/Dm)o = f(MBK)	-0.12	-0.70	<50	0.03	11
189		(W/Dx)o = f(MBD)	0.78	1.47	80	0.19	9
190		(W/Dm)o = f(MBD)	0.46	0.74	50	0.06	9
191		(W/Dx)fb = f(%CBK)	0.16	0.54	<50	0.03	11
192		(W/Dm)fb = f(%CBK)	-0.001	-0.003	<50	0.000001	11
193		(W/Dx)fb = f(%SCBK)	-0.25	-1.36	50	0.17	11
194		(W/Dm)fb = f(%SCBK)	-0.32	-1.51	80	0.20	11
195		(W/Dx)fb = f(Mfb)	-0.33	-3.02	98	0.50	11
196		(W/Dm)fb = f(Mfb)	-0.38	-2.81	95	0.47	11
197		(W/Dx)fb = f(MBK)	0.07	0.84	50	0.07	11
198		(W/Dm)fb = f(MBK)	0.09	0.88	50	0.08	11
199		(W/Dx)fb = f(MBD)	0.06	0.18	<50	0.004	9
200		(W/Dm)fb = f(MBD)	0.05	0.12	<50	0.002	9
201	Reaches D,E, & F	(W/Dx)o = f(%CBK)	0.69	2.24	95	0.26	16
202		(W/Dm)o = f(%CBK)	0.56	1.86	90	0.20	16
203		(W/Dx)o = f(%SCBK)	0.60	1.90	90	0.21	16
204		(W/Dm)o = f(%SCBK)	0.47	1.53	80	0.14	16
205		(W/Dx)o = f(Mo)	-0.48	-7.41	99.8	0.80	16
206		(W/Dm)o = f(Mo)	-0.42	-5.69	99.8	0.70	16
207		(W/Dx)o = f(MBK)	-0.18	-0.98	50	0.06	16
208		(W/Dm)o = f(MBK)	-0.12	-0.70	50	0.03	16
209		(W/Dx)o = f(MBD)	0.13	5.33	99.8	0.67	14
210		(W/Dm)o = f(MBD)	0.11	3.78	99	0.51	14
211		(W/Dx)fb = f(%CBK)	0.41	2.23	95	0.26	16
212		(W/Dm)fb = f(%CBK)	0.16	0.73	50	0.04	16
213		(W/Dx)fb = f(%SCBK)	0.18	0.84	50	0.05	16
214		(W/Dm)fb = f(%SCBK)	-0.04	-0.17	<50	0.002	16
215		(W/Dx)fb = f(Mfb)	-0.36	-7.17	99.8	0.79	16
216		(W/Dm)fb = f(Mfb)	-0.30	-4.04	99.8	0.54	16
217		(W/Dx)fb = f(MBK)	-0.004	-0.04	<50	0.0001	16
218		(W/Dm)fb = f(MBK)	0.08	0.69	<50	0.03	16

App. IVa continued:

Ref. No.	Data set	Relation	Exponent	Student's t of exponent	Two-tailed significance of t (%)	Coefficient of determination, r^2	Sample size
219	Reaches D,E,&F	(W/Dx)fb = f(MBD)	0.08	5.27	99.8	0.67	14
220		(W/Dm)fb = f(MBD)	0.06	2.84	98	0.37	14
221	Reaches A to F	(W/Dx)o = f(%CBK)	0.11	0.89	50	0.02	42
222		(W/Dm)o = f(%CBK)	0.06	0.51	< 50	0.006	42
223		(W/Dx)o = f(%CBD)	-0.04	-0.74	50	0.01	42
224		(W/Dm)o = f(%CBD)	-0.04	-0.80	50	0.16	42
225		(W/Dx)o = f(%SCBK)	0.14	0.88	50	0.02	42
226		(W/Dm)o = f(%SCBK)	0.10	0.59	<50	0.009	42
227		(W/Dx)o = f(%SCBD)	-0.01	-0.63	<50	0.01	42
228		(W/Dm)o = f(%SCBD)	-0.02	-1.01	50	0.03	42
229		(W/Dx)o = f(Mo)	-0.07	-1.16	50	0.03	42
230		(W/Dm)o = f(Mo)	-0.04	-0.68	50	0.01	42
231		(W/Dx)o = f(MBK)	-0.02	-0.30	<50	0.002	42
232		(W/Dm)o = f(MBK)	0.004	0.07	< 50	0.0001	42
233		(W/Dx)o = f(MBD)	0.02	0.78	50	0.02	39
234		(W/Dm)o = f(MBD)	0.02	1.43	80	0.05	39
235		(W/Dx)fb = f(%CBK)	0.41	4.86	99.8	0.12	36
236		(W/Dm)fb = f(%CBK)	0.38	4.23	99.8	0.42	36
237		(W/Dx)fb = f(%CBD)	0.06	4.74	99.8	0.40	36
238		(W/Dm)fb = f(%CBD)	0.07	4.73	99.8	0.40	36
239		(W/Dx)fb = f(%SCBK)	0.54	4.46	99.8	0.38	36
240		(W/Dm)fb = f(%SCBK)	0.54	3.40	99.8	0.25	36
241		(W/Dx)fb = f(%SCBD)	0.04	2.06	95	0.11	36
242		(W/Dm)fb = f(%SCBD)	0.04	2.26	95	0.13	36
243		(W/Dx)fb = f(Mfb)	0.16	2.60	98	0.17	36
244		(W/Dm)fb = f(Mfb)	0.17	2.84	99	0.19	36
245		(W/Dx)fb = f(MBK)	-0.19	-3.80	99.8	0.30	36
246		(W/Dm)fb = f(MBK)	-0.18	-3.49	99.8	0.26	36
247		(W/Dx)fb = f(MBD)	-0.04	-2.09	95	0.12	34
248		(W/Dm)fb = f(MBD)	-0.05	-2.55	98	0.16	34

App. IVb. Meander wavelength, L, and channel width, W, relationships for the Sturgeon River reaches.

Ref. No.	Data set	Relation	Exponent	Student's t of exponent	Two-tailed significance of t (%)	Coefficient of determination, r^2	Sample size
1	Reach A, simple or small	L = f(Wo)	-0.80	-2.121	90	0.360	10
2		L = f(Wfb)	-0.06	-0.480	<50	0.021	10
3	Reach A, large or simple	L = f(Wo)	0.23	0.153	<50	0.003	10
4		L = f(Wfb)	-0.33	-1.120	50	0.136	10
5		L = f(Wvf)	0.28	1.004	50	0.112	10
6	Reach B, small and specific	L = f(Wo)	-0.08	-0.030	<50	0.0001	7
7		L = f(Wfb)	-2.82	-0.621	<50	0.161	4
8	Reach B, small and averaged	L = f(Wo)	0.20	0.105	<50	0.002	7
9		L = f(Wfb)	1.61	0.582	<50	0.145	4
10	Reach C, small or simple and specific	L = f(Wo)	0.67	0.603	<50	0.057	8
11		L = f(Wfb)	-0.47	-0.601	<50	0.107	5
12	Reach C, small or simple and averaged	L = f(Wo)	0.89	1.501	80	0.273	8
13		L = f(Wfb)	-0.28	-0.822	50	0.184	5
14	Reach C, large or simple and specific	L = f(Wo)	-0.90	-0.756	50	0.087	8
15		L = f(Wfb)	-1.62	-1.279	50	0.353	5
16	Reaches A to C, small or simple and specific	L = f(Wo)	0.79	3.440	99	0.340	25
17		L = f(Wfb)	0.38	1.713	80	0.147	19
18	Reaches A to C, small or simple and averaged	L = f(Wo)	0.75	4.290	99.8	0.444	25
19		L = f(Wfb)	0.30	1.913	90	0.177	19
20	Reaches A to C, large or simple and specific	L = f(Wo)	1.03	3.641	99.8	0.411	21
21		L = f(Wfb)	0.18	0.585	<50	0.021	18

App. IVb. continued:

Ref. No.	Data set	Relation	Exponent	Student's t of exponent	Two-tailed significance of t (%)	Coefficient of determination, r^2	Sample size
22	Reaches A to C, large only	L = f(Wo)	0.82	2.631	95	0.540	8
23		L = f(Wfb)	0.77	2.891	95	0.581	8
24		L = f(Wvf)	0.003	1.525	80	0.279	8
25	Reaches A to C, small only	L = f(Wo)	0.50	1.058	50	0.101	12
26		L = f(Wfb)	0.25	0.505	<50	0.035	9
27	Reach D, specific	L = f(Wo)	1.91	0.765	50	0.163	5
28		L = f(Wfb)	-0.33	-0.265	<50	0.023	5
29	Reach D, specific with dummy variable	L = f(Wo)	0.07	0.056	<50	0.872	5
30	Reach D, dummy only	L = f(dummy)	-0.77	-4.516	95	0.872	5
31	Reach E, specific	L = f(Wo)	0.54	0.160	<50	0.010	3
32		L = f(Wfb)	3.68	2.120	50	0.529	3
33	Reach E, averaged	L = f(Wo)	0.54	0.361	< 50	0.032	3
34		L = f(Wfb)	0.43	1.293	50	0.358	3
35	Reach F, small or simple and specific	L = f(Wo)	3.59	1.650	80	0.410	6
36		L = f(Wfb)	0.54	0.211	<50	0.015	6
37	Reach F, large or simple and specific	L = f(Wo)	0.79	0.368	< 50	0.033	6
38		L = f(Wfb)	0.22	0.113	< 50	0.003	6
39	Reach F, small or simple and specific	L = f(Wvf)	0.40	0.328	<50	0.026	6
40	Reach F, large or simple and specific	L = f(Wvf)	0.15	0.176	<50	0.008	6

App. IVb. continued:

Ref. No.	Data set	Relation	Exponent	Student's t of exponent	Two-tailed significance of t (%)	Coefficient of determination, r^2	Sample size
41	Reaches E and F, small or simple and specific	L = f(Wo)	2.48	1.438	80	0.181	9
42		L = f(Wfb)	1.98	1.415	80	0.182	9
43		L = f(Wvf)	-0.01	-0.031	<50	0.0001	9
44	Reaches A to F, small or simple and specific	L = f(Wo)	0.79	2.844	99	0.172	39
45		L = f(Wfb)	0.12	0.481	<50	0.007	33

App. IVc. Meander wavelength, L, and the width to depth ratio, W/D, relationships for the Sturgeon River reaches.

Ref. No.	Data set	Relation	Exponent	Student's t of exponent	Two-tailed significance of t (%)	Coefficient of determination, r^2	Sample size
1	Reach A, small or simple	L = f((W/Dx)o)	-0.39	-1.706	80	0.267	10
2		L = f((W/Dm)o)	-0.38	-1.885	90	0.307	10
3		L = f((W/Dx)fb)	-0.51	-2.083	90	0.352	10
4		L = f((W/Dm)fb)	-0.29	-1.438	80	0.205	10
5	Reach A, large or simple	L = f((W/Dx)o)	0.32	0.895	50	0.091	10
6		L = f((W/Dm)o)	0.33	1.013	50	0.114	10
7		L = f((W/Dx)fb)	0.58	1.368	50	0.190	10
8		L = f((W/Dm)fb)	0.50	1.644	80	0.253	10
9		L = f((W/Dx)vf)	0.28	0.720	50	0.061	10
10		L = f((W/Dm)vf)	0.08	0.244	<50	0.007	10
11	Reach B, small and specific	L = f((W/Dx)o)	0.52	0.459	<50	0.040	7
12		L = f((W/Dm)o)	-0.15	-0.114	<50	0.003	7
13	Reach B, small and averaged	L = f((W/Dx)o)	0.16	0.210	<50	0.009	7
14		L = f((W/Dm)o)	0.20	0.234	<50	0.011	7
15	Reach B, small and specific	L = f((W/Dx)fb)	2.98	4.456	95	0.909	4
16		L = f((W/Dm)fb)	2.62	1.797	50	0.617	4
17	Reach B, small and averaged	L = f((W/Dx)fb)	0.87	0.729	<50	0.210	4
18		L = f((W/Dm)fb)	0.48	0.350	<50	0.058	4
19	Reach C, small or simple and specific	L = f((W/Dx)o)	-0.01	-0.021	<50	0.00007	8
20		L = f((W/Dm)o)	-0.51	-0.706	<50	0.077	8
21	Reach C, small or simple and averaged	L = f((W/Dx)o)	0.62	3.693	98	0.695	8

App. IVc.continued:

Ref. No.	Data set	Relation	Exponent	Student's t of exponent	Two-tailed significance of t (%)	Coefficient of determination, r^2	Sample size
22	Reach C, small or simple and averaged	L = f((W/Dm)o)	0.86	2.911	95	0.585	8
23	Reach C, small or simple and specific	L = f((W/Dx)fb)	0.73	2.659	90	0.708	5
24		L = f((W/Dm)fb)	0.87	2.280	80	0.634	5
25	Reach C, small or simple and averaged	L = f((W/Dx)fb)	0.30	1.941	80	0.557	5
26		L = f((W/Dm)fb)	0.30	1.346	50	0.376	5
27	Reach C, large or simple	L = f((W/Dx)o)	0.64	0.726	50	0.081	8
28		L = f((W/Dm)o)	0.93	0.707	<50	0.077	8
29		L = f((W/Dx)fb)	1.35	2.491	90	0.674	5
30		L = f((W/Dm)fb)	1.89	4.028	95	0.844	5
31	Reaches A to C, large only	L = f((W/Dx)o)	0.58	2.536	95	0.517	8
32		L = f((W/Dm)o)	0.50	2.477	95	0.506	8
33		L = f((W/Dx)fb)	0.52	1.107	50	0.170	8
34		L = f((W/Dm)fb)	0.58	1.292	50	0.218	8
35	Peaches A to C, small only	L = f((W/Dx)o)	0.34	1.078	50	0.104	12
36		L = f((W/Dm)o)	0.23	0.780	50	0.057	12
37	Reaches A to C, large or simple	L = f((W/Dx)o)	0.76	3.209	99	0.351	21
38		L = f((W/Dm)o)	0.71	2.903	99	0.307	21
39		L = f((W/Dx)fb)	1.15	3.345	99	0.411	18
40		L = f((W/Dm)fb)	1.07	3.063	99	0.370	18
41	Reaches A to C, small or simple and specific	L = f((W/Dx)o)	0.51	2.676	98	0.237	25
42		L = f((W/Dm)o)	0.46	2.323	95	0.190	25

App. IVc. continued:

Ref. No.	Data set	Relation	Exponent	Student's t of exponent	Two-tailed significance of t (%)	Coefficient of determination, r^2	Sample size
43	Reaches A to C, small or simple and averaged	L = f((W/Dx)o)	0.52	3.594	99.8	0.360	25
44		L = f((W/Dm)o)	0.49	3.248	99	0.314	25
45	Reaches A to C, small or simple and specific	L = f((W/Dx) fb)	0.73	2.396	95	0.252	19
46		L = f((W/Dm) fb)	0.50	1.565	80	0.126	19
47	Reaches A to C, small or simple and averaged	L = f((W/Dx) fb)	0.33	1.385	80	0.101	19
48		L = f((W/Dm) fb)	0.18	0.759	50	0.033	19
49	Reach D, specific	L = f((W/Dx)o)	0.26	0.227	<50	0.017	5
50		L = f((W/Dm)o)	0.45	0.506	<50	0.079	5
51		L = f((W/Dx) fb)	-1.55	-0.997	50	0.249	5
52		L = f((W/Dm) fb)	-0.70	-0.771	50	0.165	5
53	Reach E, specific	L = f((W/Dx)o)	-2.03	-1.264	50	0.348	3
54		L = f((W/Dm)o)	-1.25	-0.973	<50	0.240	3
55	Reach E, averaged	L = f((W/Dx)o)	-0.02	-0.057	<50	0.001	3
56		L = f((W/Dm)o)	0.02	0.086	<50	0.002	3
57	Reach E, specific	L = ((W/Dx) fb)	-1.14	-0.741	<50	0.155	3
58		L = f((W/Dm) fb)	-1.26	-1.067	50	0.275	3
59	Reach E, averaged	L = f((W/Dx) fb)	0.34	1.892	50	0.544	3
60		L = f((W/Dm) fb)	0.26	1.572	50	0.452	3
61	Reach F, small or simple and specific	L = f((W/Dx)o)	1.11	1.535	80	0.371	6
62		L = f((W/Dm)o)	0.84	1.105	50	0.234	6
63	Reach F, large or simple and specific	L = f((W/Dx)o)	0.83	1.448	50	0.344	6
64		L = f((W/Dm)o)	0.81	1.510	50	0.363	6

App. IVc. continued:

Ref. No.	Data set	Relation	Exponent	Student's t of exponent	Two-tailed significance of t (%)	Coefficient of determination, r^2	Sample size
65	Reach F, small or simple and specific	L = f((W/Dx) fb)	0.49	0.236	<50	0.014	6
66		L = f((W/Dm) fb)	1.27	0.733	<50	0.119	6
67	Reach F large or simple and specific	L = f((W/Dx) fb)	-0.33	-0.204	<50	0.010	6
68		L = f((W/Dm) fb)	-1.48	-1.197	50	0.264	6
69		L = f((W/Dx) vf)	1.62	1.399	50	0.329	6
70		L = f((W/Dm) vf)	0.40	0.329	<50	0.026	6
71	Reaches E and F, small or simple and specific	L = f((W/Dx)o)	0.39	0.637	<50	0.043	9
72		L = f((W/Dm)o)	0.20	0.355	<50	0.014	9
73		L = f((W/Dx) fb)	-0.49	-0.440	<50	0.021	9
74		L = f((W/Dm) fb)	-0.32	-0.342	<50	0.013	9
75	Reaches D to F, small or simple and specific	L = f((W/Dx)o)	0.33	1.088	50	0.078	14
76		L = f((W/Dm)o)	0.32	0.973	50	0.063	14
77		L = f((W/Dx) fb)	0.08	0.162	<50	0.002	14
78		L = f((W/Dm) fb)	-0.04	-0.083	<50	0.0005	14
79	Reaches A to F, small or simple and specific	L = f((W/Dx)o)	0.47	2.638	98	0.151	39
80		L = f((W/Dm)o)	0.42	2.232	95	0.113	39
81		L = f((W/Dx) fb)	0.75	3.593	99.8	0.281	33
82		L = f((W/Dm) fb)	0.63	2.933	99	0.207	33

App. IVd. Radius of curvature, Rc, and channel width, W, relationships for the Sturgeon River reaches.

Ref. No.	Data set	Relation	Exponent	Student's t of exponent	Two-tailed significance of t (%)	Coefficient of determination, r^2	Sample size
1	Reach A, small or simple	Rc = f(Wo)	0.07	0.116	<50	0.002	10
2		Rc = f(Wfb)	0.28	1.830	90	0.202	15
3	Reach B, small or simple and specific	Rc = f(Wo)	0.99	0.320	<50	0.021	7
4		Rc = f(Wfb)	-1.13	-0.204	<50	0.020	4
5	Reach B, small or simple and averaged	Rc = f(Wo)	1.20	0.672	< 50	0.083	7
6		Rc = f(Wfb)	2.54	1.166	50	0.401	4
7	Reach C, small or simple and specific	Rc = f(Wo)	0.72	0.417	<50	0.028	8
8		Rc = f(Wfb)	-2.22	-2.138	80	0.604	5
9	Reach C, small or simple and averaged	Rc = f(Wo)	1.10	1.574	80	0.292	5
10		Rc = f(Wfb)	-0.29	-1.028	50	0.260	5
11	Reach D, specific	Rc = f(Wo)	3.33	0.754	50	0.159	5
12		Rc = f(Wfb)	-0.11	-0.052	<50	0.001	5
13	Reach E, specific	Rc = f(Wo)	1.52	0.440	<50	0.050	4
14		Rc = f(Wfb)	1.23	0.498	<50	0.076	4
15	Reach E, averaged	Rc = f(Wo)	1.51	0.930	< 50	0.225	3
16		Rc = f(Wfb)	1.01	0.789	<50	0.172	3
17	Reach F, small or simple and specific	Rc = f(Wo)	5.61	1.710	80	0.420	6
18		Rc = f(Wfb)	4.93	1.650	80	0.403	6
19	Reaches A to C, small or simple and specific	Rc = f(Wo)	1.19	4.385	99.8	0.455	25
20		Rc = f(Wfb)	0.72	2.671	98	0.296	19

App. IVd continued:

Ref. No.	Data set	Relation	Exponent	Student's t of exponent	Two-tailed significance of t (%)	Coefficient of determination, r^2	Sample size
21	Reaches A to C, small or simple & averaged	Rc = f(Wo)	1.03	5.918	99.8	0.604	25
22		Rc = f(Wfb)	0.50	3.198	99	0.376	41
23	Reaches D to F, small or simple & specific	Rc = f(Wo)	3.39	1.991	90	0.221	14
24		Rc = f(Wfb)	0.85	0.747	50	0.038	14
25	Reaches A to F, small or simple & specific	Rc = f(Wo)	1.21	3.502	99.8	0.239	41
26		Rc = f(Wfb)	0.43	1.402	80	0.056	35

App. IVe. Radius of curvature, Rc, and the width to depth ratio, W/D, relationships for the Sturgeon River reaches.

Ref. No.	Data set	Relation	Exponent	Student's t of exponent	Two-tailed significance of t (%)	Coefficient of determination, r^2	Sample size
1	Reach A, small or simple	Rc = f((W/Dx)o)	0.30	0.932	50	0.098	10
2		Rc = f((W/Dm)o)	0.27	0.935	50	0.099	10
3		Rc = f((W/Dx)fb)	-0.14	-0.364	<50	0.016	10
4		Rc = f((W/Dm)fb)	0.22	0.811	50	0.076	10
5	Reach B, small or simple and specific	Rc = f((W/Dx)o)	0.98	0.834	50	0.122	7
6		Rc = f((W/Dm)o)	0.43	0.317	<50	0.020	7
7		Rc = f((W/Dx)fb)	3.37	4.421	95	0.907	4
8		Rc = f((W/Dm)fb	3.64	5.477	95	0.937	4
9	Reach B, small or simple and averaged	Rc = f((W/Dx)o)	0.49	0.691	<50	0.087	7
10		Rc = f((W/Dm)o)	0.66	0.878	50	0.134	7
11		Rc = f((W/Dx)fb)	0.92	0.846	50	0.263	4
12		Rc = f((W/Dm)fb)	0.84	0.693	<50	0.193	4
13	Reach C, small or simple and specific	Rc = f((W/Dx)o)	0.29	0.383	<50	0.023	8
14		Rc = f((W/Dm)o)	0.16	0.139	<50	0.003	8
15		Rc = f((W/Dx)fb)	1.25	4.443	95	0.868	5
16		Rc = f((W/Dm)fb)	1.62	6.873	99	0.940	5
17	Reach C, small or simple and averaged	Rc = f((W/Dx)o)	0.56	1.983	90	0.396	8
18		Rc = f((W/Dm)o)	0.82	1.872	80	0.369	8
19		Rc = f((W/Dx)fb)	0.32	4.573	95	0.875	5
20		Rc = f((W/Dm)fb	0.42	7.334	98	0.947	5

App. IVe. continued:

Ref. No.	Data set	Relation	Exponent	Student's t of exponent	Two-tailed significance of t (%)	Coefficient of determination, r^2	Sample size
21	Reach D, specific	Rc = f((W/Dx)o)	0.50	0.254	<50	0.021	5
22		Rc = f((W/Dm)o)	0.93	0.607	<50	0.109	5
23		Rc = f((W/Dx)fb)	-2.36	-0.828	50	0.186	5
24		Rc = f((W/Dm)fb)	-0.90	-0.538	<50	0.088	5
25	Reach E, specific	Rc = f((W/Dx)o)	-1.84	-1.107	50	0.290	3
26		Rc = f((W/Dm)o)	-1.08	-0.815	<50	0.181	3
27		Rc = f((W/Dx)fb)	-0.42	-0.256	<50	0.021	3
28		Rc = f((W/Dm)fb)	-0.67	-0.509	<50	0.080	3
29	Reach E, averaged	Rc = f((W/Dx)o)	0.78	0.802	<50	0.177	3
30		Rc = f((W/Dm)o)	0.57	0.788	<50	0.172	3
31	Reach F, small or simple and specific	Rc = f((W/Dx)o)	1.62	1.430	50	0.338	6
32		Rc = f((W/Dm)o)	1.17	0.979	50	0.193	6
33		Rc = f((W/Dx)fb)	-0.16	-0.051	<50	0.0007	6
34		Rc = f((W/Dm)fb)	1.48	0.540	<50	0.068	6
35	Reaches A to C, small or simple and specific	Rc = f((W/Dx)o)	0.91	4.220	99.8	0.436	25
36		Rc = f((W/Dm)o)	0.87	3.979	99.8	0.408	25
37		Rc = f((W/Dx)fb)	1.27	3.570	99	0.428	19
38		Rc = f((W/Dm)fb)	1.18	3.264	99	0.385	19
39	Reaches A to C, small or simple and averaged	Rc = f((W/Dx)o)	0.79	5.695	99.8	0.585	25
40		Rc = f((W/Dm)o)	0.78	5.620	99.8	0.579	25
41		Rc = f((W/Dx)fb)	0.54	2.108	90	0.207	19

App. IVe. continued:

Ref. No.	Data set	Relation	Exponent	Student's t of exponent	Two-tailed significance of t (%)	Coefficient of determination, r^2	Sample size
42	Reaches A to C, small or simple and averaged	Rc = f((W/Dm)fb)	0.58	2.387	95	0.251	19
43	Reaches D to F, small or simple and specific	Rc = f((W/Dx)o)	0.35	0.805	50	0.044	14
44		Rc = f((W/Dm)o)	0.38	0.824	50	0.046	14
45		Rc = f((W/Dx)fb)	-0.15	-0.201	<50	0.003	14
46		Rc = f((W/Dm)fb)	-0.09	-0.118	<50	0.001	14
47	Reaches A to F, small or simple and specific	Rc = f((W/Dx)o)	0.73	3.253	99	0.213	41
48		Rc = f((W/Dm)o)	0.72	3.093	99	0.197	41
49		Rc = f((W/Dx)fb)	0.94	3.424	99.8	0.262	35
50		Rc = f((W/Dm)fb	0.91	3.360	99.8	0.255	35

App. IVf. Sinuosity, Sin and channel width, W, relationships for the Sturgeon River reaches.

Ref. No.	Data set	Relation	Exponent	Student's t of exponent	Two-tailed significance of t (%)	Coefficient of determination, r^2	Sample size
1	Reaches A to C	Sin = f(Wo)	-0.70	-4.115	95	0.424	5
2	"	Sin = f(Wfb)	-0.46	-3.101	90	0.361	5
3	Reaches D to F	Sin = f(Wo)	-0.94	-1.445	80	0.130	8
4	"	Sin = f(Wfb)	0.55	1.407	50	0.124	8
5	Reaches A to F	Sin = f(Wo)	-0.36	-2.763	98	0.188	13
6	"	Sin = f(Wfb)	-0.71	-4.653	99.8	0.357	13

App. IVg. Sinuosity, Sin, and the width to depth ratio, W/D, relationships for the Sturgeon River reaches.

Ref. No.	Data set	Relation	Exponent	Student's t of exponent	Two-tailed significance of t (%)	Coefficient of determination, r^2	Sample size
1	Reaches A to C	Sin = f(W/Dx)o	-0.45	-3.046	90	0.287	5
2	"	Sin = f(W/Dm)O	-0.44	-2.957	90	0.275	5
3	"	Sin = f(W/Dx)fb	-0.33	-1.260	50	0.085	5
4	"	Sin = f(W/Dm)fb	-0.23	-0.877	50	0.043	5
5	Reaches D to F	Sin = f(W/Dx)o	-0.13	-0.822	50	0.046	8
6	"	Sin = f(W/Dm)o	-0.13	-0.748	50	0.038	8
7	"	Sin = f(W/Dx)fb	-0.17	-0.658	50	0.030	8
8	"	Sin = f(W/Dm)fb	-0.10	-0.378	50	0.010	8
9	Reaches A to F	Sin = f(W/Dx)o	-0.33	-2.989	98	0.186	13
10	"	Sin = f(W/Dm)o	-0.33	-2.965	98	0.184	13
11	"	Sin = f(W/Dx)fb	-0.14	-0.953	50	0.027	13
12	"	Sin = f(W/Dm)fb	-0.08	-0.599	50	0.011	13

App. IVh. Meander amplitude, Amp, and channel width, W, relationships for the Sturgeon River reaches.

Ref. No.	Data set	Relation	Exponent	Student's t of exponent	Two-tailed significance of t (%)	Coefficient of determination, r^2	Sample size
1	Reach A, small or simple	Amp = f(Wo)	-1.65	-2.320	95	0.290	10
2		Amp = f(Wfb)	0.17	0.666	<50	0.053	10
3	Reach A, large or simple	Amp = f(Wo)	0.23	0.153	<50	0.003	10
4		Amp = f(Wfb)	-0.88	-1.424	80	0.202	10
5		Amp = f(Wvf)	0.89	1.590	80	0.240	10
6	Reach B, small or simple and specific	Amp = f(Wo)	-0.80	-0.170	<50	0.006	7
7		Amp = f(Wfb)	-4.79	-0.775	<50	0.231	4
8	Reach B, small or simple and averaged	Amp = f(Wo)	-1.13	-0.376	<50	0.027	7
9		Amp = f(Wfb)	0.72	0.158	<50	0.012	4
10	Reach C, small or simple and specific	Amp = f(Wo)	3.02	0.989	50	0.140	8
11		Amp = f(Wfb)	-1.09	-0.543	<50	0.090	5
12	Reach C, small or simple and averaged	Amp = f(Wo)	1.72	2.775	95	0.562	8
13		Amp = f(Wfb)	-0.38	-0.639	<50	0.120	5
14	Reach C, large or simple and specific	Amp = f(Wo)	0.81	0.311	<50	0.016	8
15		Amp = f(Wfb)	-0.74	-0.206	<50	0.014	5
16	Reach D, specific	Amp = f(Wo)	0.94	0.639	<50	0.120	5
17		Amp = f(Wfb)	-0.11	-0.052	<50	0.0009	5

App. IVh. continued:

Ref. No.	Data set	Relation	Exponent	Student's t of exponent	Two-tailed significance of t (%)	Coefficient of determination, r^2	Sample size
18	Reach E, specific	Amp = f(Wo)	-0.73	-0.220	<50	0.010	4
19		Amp = f(Wfb)	1.23	0.498	<50	0.076	3
20	Reach E, averaged	Amp = f(Wo)	-0.96	-0.908	<50	0.215	3
21	Reach F, small or simple and specific	Amp = f(Wo)	2.13	1.320	50	0.300	6
22		Amp = f(Wfb)	4.93	1.645	80	0.403	6
23	Reach F, large or simple and specific	Amp = f(Wo)	-0.97	-0.208	<50	0.011	6
24		Amp = f(Wfb)	2.36	0.582	<50	0.078	6
25		Amp = f(Wvf)	2.32	1.385	50	0.324	6
26	Reaches A to C, small or simple and specific	Amp = f(Wo)	0.07	0.156	<50	0.001	25
27		Amp = f(Wfb)	-0.24	-0.646	<50	0.024	19
28	Reaches A to C, small or simple and specific	Amp = f(Wo)	-0.12	-0.376	<50	0.006	25
29		Amp = f(Wfb)	-0.17	-0.599	<50	0.021	19
30	Reaches A to C, large or simple	Amp = f(Wo)	0.54	0.887	50	0.040	21
31		Amp = f(Wfb)	-0.73	-1.795	90	0.168	18
32		Amp = f(Wvf)	1.03	1.740	80	0.159	18
33	Reaches A to C, large only	Amp = f(Wo)	-0.35	-0.833	50	0.104	8
34		Amp = f(Wfb)	-0.24	-0.608	<50	0.058	8
35	Reaches D to F, small or simple and specific	Amp = f(Wo)	1.69	1.574	80	0.150	16
36		Amp = f(Wfb)	0.85	0.747	50	0.038	16
37	Reaches A to F, small or simple and specific	Amp = f(Wo)	0.08	0.200	<50	0.001	41
38		Amp = f(Wfb)	-0.48	-1.654	80	0.077	35

App. IVi. Meander amplitude, Amp, and width to depth, W/D, relationships for the Sturgeon River reaches.

Ref. No.	Data set	Relation	Exponent	Student's t of exponent	Two-tailed significance of t (%)	Coefficient of determination, r^2	Sample size
1	Reach A, small or simple	Amp = f(W/Dx)o	-1.35	-2.188	90	0.375	10
2		Amp = f(W/Dm)o	-1.37	-2.647	95	0.467	10
3		Amp = f(W/Dx) fb	-1.26	-1.612	80	0.245	10
4		Amp = f(W/Dm) fb	-1.10	-2.018	90	0.337	10
5	Reach A, large or simple	Amp = f(W/Dx)o	0.26	0.306	<50	0.012	10
6		Amp = f(W/Dm)o	0.35	0.458	<50	0.026	10
7		Amp = f(W/Dx) fb	0.99	1.012	50	0.113	10
8		Amp = f(W/Dm) fb	0.60	0.806	50	0.075	10
9	Reach B, small or simple & specific	Amp = f(W/Dx)o	0.27	0.154	<50	0.005	7
10		Amp = f(W/Dm)o	-0.58	-0.300	<50	0.018	7
11		Amp = f(W/Dx) fb	2.62	1.029	50	0.346	4
12		Amp = f(W/Dm) fb	0.99	0.301	< 50	0.043	4
13	Reach B, small or simple & averaged	Amp = f(W/Dx)o	-0.19	-0.158	<50	0.005	7
14		Amp = f(W/Dm)o	-0.35	-0.263	<50	0.014	7
15		Amp = f(W/Dx) fb	1.08	0.569	<50	0.139	4
16		Amp = f(W/Dm) fb	0.17	0.077	<50	0.003	4
17	Reach C, small or simple & specific	Amp = f(W/Dx)o	-0.30	-0.230	<50	0.007	5
18		Amp = f(W/Dm)o	-2.01	-0.997	50	0.142	5
19		Amp = f(W/Dx) fb	0.38	0.303	<50	0.030	8
20		Amp = f(W/Dm) fb	0.27	0.169	<50	0.009	8

App. IVi continued:

Ref. No.	Data set	Relation	Exponent	Student's t of exponent	Two-tailed significance of t (%)	Coefficient of determination, r^2	Sample size
21	Reach C, small or simple & average	Amp = f(W/Dx)o	0.77	2.980	95	0.597	8
22		Amp = f(W/Dm)o	0.96	2.061	90	0.415	8
23		Amp = f(W/Dx) fb	0.64	6.043	99	0.924	5
24		Amp = f(W/Dm) fb	0.75	3.446	95	0.798	5
25	Reach C, large or simple & specific	Amp = f(W/Dx)o	0.44	0.230	<50	0.009	8
26		Amp = f(W/Dm)o	0.14	0.048	<50	0.0004	8
27		Amp = f(W/Dx) fb	2.21	1.241	50	0.339	5
28		Amp = f(W/Dm) fb	3.44	1.821	80	0.525	5
29	Reach D, specific	Amp = f(W/Dx)o	-0.19	-0.302	<50	0.300	5
30		Amp = f(W/Dm)o	-0.02	-0.042	<50	0.0006	5
31		Amp = f(W/Dx) fb	-1.07	-1.308	50	0.363	5
32		Amp = f(W/Dm) fb	-0.69	-1.728	80	0.499	5
33	Reach E, specific	Amp = f(W/Dx)o	-1.84	-1.267	50	0.348	3
34		Amp = f(W/Dm)o	-1.19	-1.046	50	0.267	3
35		Amp = f(W/Dx) fb	-1.72	-1.509	50	0.431	3
36		Amp = f(W/Dm) fb	-1.66	-2.075	50	0.589	3
37	Reach E, averaged	Amp = f(W/Dx)o	-0.52	-0.823	<50	0.180	3
38		Amp = f(W/Dm)o	-0.38	-0.803	<50	0.177	3
39	Reach F, small or simple & specific	Amp = f(W/Dx)o	0.47	0.817	50	0.143	6
40		Amp = f(W/Dm)o	0.38	0.672	<50	0.101	6
41		Amp = f(W/Dx) fb	1.21	0.936	50	0.180	6

App. IVi. continued:

Ref. No.	Data set	Relation	Exponent	Student's t of exponent	Two-tailed significance of t (%)	Coefficient of determination, r^2	Sample size
42	Reach F, small or simple & specific	Amp = f(W/Dm) fb	1.78	1.952	80	0.488	6
43	Reach F, large or simple & specific	Amp = f(W/Dx)o	-0.07	-0.047	<50	0.0006	6
44		Amp = f(W/Dm)o	0.27	0.189	<50	0.009	6
45	Reaches D to F, small or simple & specific	Amp = f(W/Dx)o	0.29	1.135	50	0.084	16
46		Amp = f(W/Dm)o	0.24	0.851	50	0.049	16
47		Amp = f(W/Dx) fb	0.35	0.805	50	0.044	16
48		Amp = f(W/Dm) fb	0.08	0.190	<50	0.003	16
49	Reaches A to C, small or simple & specific	Amp = f(W/Dx)o	-0.14	-0.380	<50	0.006	25
50		Amp = f(W/Dm)o	-0.29	-0.783	50	0.026	25
51		Amp = f(W/Dx) fb	-0.19	-0.345	<50	0.007	19
52		Amp = f(W/Dm) fb	-0.58	-1.110	50	0.068	19
53	Reaches A to C, small or simple & averaged	Amp = f(W/Dx)o	-0.14	-0.566	<50	0.014	25
54		Amp = f(W/Dm)o	-0.24	-0.967	50	0.039	25
55	Reaches A to C, large or simple	Amp = f(W/Dx)o	0.34	0.684	<50	0.024	21
56		Amp = f(W/Dm)o	0.21	0.415	<50	0.009	21
57		Amp = f(W/Dx) fb	0.13	0.258	<50	0.011	8
58		Amp = f(W/Dm) fb	0.17	0.346	<50	0.020	8
59	Reaches A to C, large only	Amp = f(W/Dx)o	-0.16	-0.514	<50	0.042	8
60		Amp = f(W/Dm)o	-0.14	-0.520	<50	0.043	8

App. IVi. continued:

Ref. No.	Data set	Relation	Exponent	Student's t of exponent	Two-tailed significance of t (%)	Coefficient of determination, r^2	Sample size
61	Reaches A to C, large only	Amp = f(W/Dx) fb	0.93	1.530	80	0.128	18
62		Amp = f(W/Dm) fb	0.83	1.371	80	0.105	18
63	Reaches A to F, small or simple & specific	Amp = f(W/Dx) o	0.05	0.174	<50	0.0008	41
64		Amp = f(W/Dm) o	-0.11	-0.395	<50	0.004	41
65		Amp = f(W/Dx) fb	0.49	1.675	80	0.078	35
66		Amp = f(W/Dm) fb	0.28	0.943	50	0.026	35

App. IVj. Relations between the radius of curvature, Rc, wavelength, L, amplitude, Amp, and sinuosity, Sin, and the channel slope, Sc, or the valley slope, Sv, for the Sturgeon River reaches.

Ref. No.	Data set	Relation	Exponent	Student's t of exponent	Two-tailed significance of t (%)	Coefficient of determination, r^2	Sample size
1	Reaches A to C, small or simple & specific data	Rc = f(Sc)	-1.06	-2.749	90	0.247	5
2		Rc = f(Sv)	-0.72	-4.292	95	0.445	5
3		L = f(Sc)	-0.74	-2.396	90	0.200	5
4		L = f(Sv)	-0.55	-4.106	95	0.423	5
5		Amp = f(Sc)	-0.07	-0.144	<50	0.0009	5
6		Amp = f(Sv)	-0.18	-0.692	<50	0.020	5
7		Sin = f(Sc)	0.88	5.542	98	0.572	5
8		Sin = f(Sv)	0.50	7.639	99	0.717	5
9	Reaches A to C, small or simple & averaged data	Rc = f(Sc)	-0.77	-3.027	90	0.285	5
10		Rc = f(Sv)	-0.51	-4.632	98	0.483	5
11		L = f(Sc)	-0.49	-2.110	80	0.162	5
12		L = f(Sv)	-0.38	-3.676	95	0.370	5
13		Amp = f(Sc)	0.24	0.685	<50	0.020	5
14		Amp = f(Sv)	0.05	0.274	<50	0.003	5
15	Reaches A to C, simple or large	L = f(Sv)	-0.60	-3.101	90	0.336	5
16	Reaches D to F, small or simple & specific	Rc = f(Sc)	0.28	1.211	50	0.095	6
17		Rc = f(Sv)	-0.02	-0.045	<50	0.0001	4
18		L = f(Sc)	0.17	1.054	<50	0.074	6
19		L = f(Sv)	0.08	0.321	<50	0.007	4

App. IVj. continued:

Ref. No.	Data set	Relation	Exponent	Student's t of exponent	Two-tailed significance of t (%)	Coefficient of determination, r^2	Sample size
20	Reaches D to F, small or simple & specific	Amp = f(Sc)	0.14	1.009	<50	0.068	6
21		Amp = f(Sv)	0.27	1.237	50	0.099	4
22		Sin = f(Sc)	-0.26	-5.124	99	0.652	6
23		Sin = f(Sv)	-0.27	-2.323	90	0.278	4
24	Reaches A to D, small or simple & specific	Rc = f(Sc)	-0.51	-2.127	90	0.149	7
25		Rc = f(Sv)	-0.61	-4.576	99	0.428	7
26		L = f(Sc)	-0.50	-3.001	95	0.243	7
27		L = f(Sv)	-0.52	-5.402	99	0.510	7
28		Amp = f(Sc)	-0.40	-1.416	50	0.067	7
29		Amp = f(Sv)	-0.32	-1.610	80	0.085	7
30		Sin = f(Sc)	0.29	2.412	90	0.172	7
31		Sin = f(Sv)	0.36	5.341	99.8	0.505	7
32	Reaches A to F, small or simple & specific	Rc = f(Sc)	-0.19	-1.680	80	0.067	11
33		Rc = f(Sv)	-0.35	-3.516	99	0.241	9
34		L = f(Sc)	-0.18	-2.114	90	0.103	11
35		L = f(Sv)	-0.29	-3.820	99	0.272	9
36		Amp = f(Sc)	-0.15	-1.370	50	0.046	11
37		Amp = f(Sv)	-0.19	-1.775	80	0.075	9
38		Sin = f(Sc)	0.02	0.411	<50	0.004	11
39		Sin = f(Sv)	0.09	1.943	90	0.088	9

App. IVk. Wavelength, L, and the channel perimeter sediment relationships for the Sturgeon River reaches.

Ref. No.	Data set	Relation	Exponent	Student's t of exponent	Two-tailed significance of t (%)	Coefficient of determination, r^2	Sample size
1	Reach A, small or simple	L = f(%SCBK)	2.20	1.879	80	0.370	8
2	"	L = f(%SCBD)	-0.24	-1.685	80	0.321	8
3	"	L = f(MBK)	0.09	0.375	<50	0.023	8
4	"	L = f(MBD)	0.08	1.740	80	0.335	8
5	Reach B, small or simple	L = f(%SCBK)	-8.50	-1.494	80	0.199	11
6	"	L = f(%SCBD)	-0.62	-0.723	50	0.055	11
7	"	L = f(MBK)	0.30	0.898	50	0.082	11
8	"	L = f(MBD)	0.19	0.814	50	0.069	11
9	Reach C, small or simple	L = f(%SCBK)	-0.03	-0.026	<50	0.00005	16
10	"	L = f(%SCBD)	0.20	0.242	<50	0.004	16
11	"	L = f(MBK)	-0.20	-1.347	80	0.115	16
12	"	L = f(MBD)	-0.23	-2.503	95	0.309	16
13	Reach D	L = f(%SCBK)	-0.16	-0.557	<50	0.022	16
14	"	L = f(%SCBD)	-0.35	-2.539	95	0.315	16
15	"	L = f(MBK)	0.10	0.376	<50	0.010	16
16	"	L = f(MBD)	0.39	2.906	98	0.376	16
17	Reach E	L = f(%SCBK)	0.16	0.307	<50	0.009	12
18	"	L = f(MBK)	-0.11	-0.645	<50	0.040	12

App. IVk. continued:

Ref. No.	Data set	Relation	Exponent	Student's t of exponent	Two-tailed significance of t (%)	Coefficient of determination, r^2	Sample size
19	Reach E	L = f(MBD)	1.21	0.850	50	0.067	4
20	Reach F	L = f(%SCBK)	0.14	0.488	<50	0.016	17
21	"	L = f(MBK)	-0.01	-0.064	<50	0.0003	17
22	"	L = f(MBD)	1.24	1.215	50	0.090	3
23	Reaches E and F	L = f(%SCBK)	0.23	1.070	50	0.041	29
24	"	L = f(MBK)	-0.08	-0.777	50	0.022	29
25	"	L = f(MBD)	0.53	0.703	<50	0.018	7
26	Reaches A to C	L = f(%SCBK)	-1.40	-1.296	50	0.048	35
27	"	L = f(%SCBD)	-0.58	-2.334	95	0.142	35
28	"	L = f(MBK)	0.07	0.603	<50	0.011	35
29	"	L = f(MBD)	0.10	1.603	80	0.072	35
30	Reaches A to F	L = f(%SCBK)	0.47	4.310	99.8	0.192	80
31	"	L = f(%SCBD)	0.04	2.445	98	0.071	80
32	"	L = f(MBK)	-0.18	-4.438	99.8	0.202	80
33	"	L = f(MBD)	-0.04	-2.748	99	0.088	58
34	Reaches B to F	L = f(%SCBK)	0.34	3.209	99	0.131	70
35	"	L = f(%SCBD)	0.02	1.242	50	0.022	70
36	"	L = f(MBK)	-0.14	-3.707	99.8	0.168	70
37	"	L = f(MBD)	-0.03	-2.021	95	0.057	48

App. IVk. continued:

Ref. No.	Data set	Relation	Exponent	Student's t of exponent	Two-tailed significance of t (%)	Coefficient of determination, r^2	Sample size
38	Reaches A to C, large or simple	L = f(%SCBK)	-1.37	-0.498	<50	0.013	21
39		L = f(SCBD)	0.01	0.118	<50	0.0007	21
40		L = f(Mo)	-0.39	-1.032	50	0.053	21
41		L = f(MBK)	-0.05	-0.224	<50	0.003	21
42		L = f(MBD)	0.05	0.721	50	0.027	21
43	Reach A, large or simple	L = f(%SCBK)	0.79	0.314	<50	0.016	8
44		L = f(%SCBD)	-0.33	-1.239	50	0.204	8
45		L = f(MBK)	0.92	4.047	99	0.732	8
46		L = f(MBD)	0.16	2.126	90	0.430	8

App. IV1. Radius of curvature, Rc, and the channel perimeter sediment relationships for the Sturgeon River reaches.

Ref. No.	Data set	Relation	Exponent	Student's t of exponent	Two-tailed significance of t (%)	Coefficient of determination, r^2	Sample size
1	Reach A, small or simple	Rc = f(%SCBK)	-1.22	-0.728	50	0.081	8
2	"	Rc = f(%SCBD)	0.08	0.381	<50	0.024	8
3	"	Rc = f(MBK)	0.11	0.370	<50	0.022	8
4		Rc = f(MBD)	-0.03	-0.476	<50	0.036	8
5	Reach B, small or simple	Rc = f(%SCBK)	-8.14	-1.085	50	0.116	11
6	"	Rc = f(%SCBD)	-1.23	-1.201	50	0.138	11
7	"	Rc = f(MBK)	0.55	1.415	80	0.182	11
8	"	Rc = f(MBD)	0.32	1.111	50	0.121	11
9	Reach C, small or simple	Rc = f(%SCBK)	0.13	0.072	<50	0.0004	16
10	"	Rc = f(%SCBD)	-0.19	-0.162	<50	0.002	16
11	"	Rc = f(MBK)	-0.10	-0.464	<50	0.015	16
12	"	Rc = f(MBD)	-0.20	-1.359	80	0.117	16
13	Reach D	Rc = f(%SCBK)	-0.10	-0.265	<50	0.005	16
14	"	Rc = f(%SCBD)	-0.46	-2.484	95	0.306	16
15	"	Rc = f(MBK)	0.08	0.230	<50	0.004	16
16	"	Rc = f(MBD)	0.52	2.857	98	0.368	16
17	Reach E	Rc = f(%SCBK)	-0.31	-0.476	<50	0.022	12
18	"	Rc = f(MBK)	-0.04	-0.171	<50	0.003	12

App. IV1. continued:

Ref. No.	Data set	Relation	Exponent	Student's t of exponent	Two-tailed significance of t (%)	Coefficient of determination, r^2	Sample size
19	Reach E	Rc = f(MBD)	1.23	0.686	<50	0.045	4
20	Reach F, small or simple	Rc = f(%SCBK)	0.47	0.998	50	0.062	17
21	"	Rc = f(MBK)	-0.16	-0.716	50	0.033	17
22	"	Rc = f(MBD)	2.87	1.753	<50	0.170	3
23	Reaches E and F	Rc = f(%SCBK)	0.23	0.670	< 50	0.016	29
24	"	Rc = f(MBK)	-0.09	-0.577	<50	0.012	29
25	"	Rc = f(MBD)	2.20	2.060	90	0.136	7
26	Reaches A to C	Rc = f(%SCBK)	-2.38	-1.747	90	0.085	35
27	"	Rc = f(%SCBD)	-0.57	-1.739	90	0.084	35
28	"	Rc = f(MBK)	0.20	1.460	80	0.061	35
29	"	Rc = f(MBD)	0.12	1.477	80	0.062	35
30	Reaches A to F	Rc = f(%SCBK)	0.42	2.882	99	0.096	80
31	"	Rc = f(%SCBD)	0.01	0.712	50	0.006	80
32	"	Rc = f(MBK)	-0.13	-2.480	98	0.073	80
33	"	Rc = f(MBD)	-0.02	-0.941	50	0.011	58
34	Reaches B to F	Rc = f(%SCBK)	0.29	1.929	95	0.052	70
35	"	Rc = f(%SCBD)	-0.01	-0.413	<50	0.003	70
36	"	Rc = f(MBK)	-0.10	-1.769	90	0.044	70
37	"	Rc = f(MBD)	-0.003	-0.124	<50	0.0002	48

App. IVm. Meander amplitude, Amp, and the channel perimeter sediment relationship for the Sturgeon River reaches.

Ref. No.	Data set	Relation	Exponent	Student's t of exponent	Two-tailed significance of t (%)	Coefficient of determination, r^2	Sample size
1	Reach A, small or simple	Amp = f(%SCBK)	7.63	1.576	80	0.293	8
2	"	Amp = f(%SCBD)	-0.80	-1.372	50	0.239	8
3	"	Amp = f(MBK)	-0.36	-0.364	<50	0.022	8
4	"	Amp = f(MBD)	0.25	1.245	50	0.205	8
5	Reach B, small or simple	Amp = f(%SCBK)	-12.00	-2.194	90	0.348	11
6	"	Amp = f(%SCBD)	0.31	0.337	<50	0.012	11
7	"	Amp = f(MBK)	-0.13	-0.354	<50	0.014	11
8	"	Amp = f(MBD)	-0.05	-0.197	<50	0.004	11
9	Reach C, small or simple	Amp = f(%SCBK)	-2.22	-0.868	50	0.051	16
10	"	Amp = f(%SCBD)	0.90	0.514	<50	0.019	16
11	"	Amp = f(MBK)	-0.54	-1.831	90	0.193	16
12	"	Amp = f(MBD)	-0.49	-2.425	95	0.296	16
13	Reach D	Amp = f(%SCBK)	-0.23	-1.000	50	0.067	16
14	"	Amp = f(%SCBD)	-0.12	-0.859	50	0.050	16
15	"	Amp = f(MBK)	0.10	0.464	<50	0.015	16
16	"	Amp = f(MBD)	0.15	1.075	50	0.076	16
17	Reach E	Amp = f(%SCBK)	0.89	1.984	90	0.283	12
18	"	Amp = f(MBK)	-0.14	-0.837	50	0.065	12

App. IVm. continued:

Ref. No.	Data set	Relation	Exponent	Student's t of exponent	Two-tailed significance of t (%)	Coefficient of determination, r^2	Sample size
19	Reach E	Amp = f(MBD)	0.65	0.440	<50	0.019	4
20	Reach F, small or simple	Amp = f(%SCBK)	-0.14	-0.527	<50	0.018	17
21	"	Amp = f(MBK)	0.08	0.628	<50	0.026	17
22	"	Amp = f(MBD)	-0.11	-0.114	<50	0.0009	3
23	Reaches E and F	Amp = f(%SCBK)	0.28	1.211	50	0.052	29
24	"	Amp = f(MBK)	-0.09	-0.811	50	0.024	29
25	"	Amp = f(MBD)	-0.96	-1.208	50	0.051	7
26	Reaches A to C	Amp = f(%SCBK)	-1.13	-0.664	<50	0.013	35
27	"	Amp = f(%SCBD)	-0.56	-1.385	80	0.055	35
28	"	Amp = f(MBK)	-0.17	-0.993	50	0.029	35
29	"	Amp = f(MBD)	0.02	0.227	<50	0.002	35
30	Reaches A to F	Amp = f(%SCBK)	0.48	3.529	99.8	0.138	80
31	"	Amp = f(%SCBD)	0.06	3.340	99.8	0.125	80
32	"	Amp = f(MBK)	-0.22	-4.611	99.8	0.214	80
33	"	Amp = f(MBD)	-0.07	-3.710	99.8	0.150	58
34	Reaches B to F	Amp = f(%SCBK)	0.38	2.973	99	0.115	70
35	"	Amp = f(%SCBD)	0.05	2.929	99	0.112	70
36	"	Amp = f(MBK)	-0.19	-4.346	99.8	0.217	70
37	"	Amp = f(MBD)	-0.06	-3.813	99.8	0.176	48

App. IVa. continued:

Ref. No.	Data set	Relation	Exponent	Student's t of exponent	Two-tailed significance of t (%)	Coefficient of determination, r^2	Sample size
38	Reaches A to C, large or simple	Amp = f(%SCBK)	4.34	0.945	50	0.045	21
39	"	Amp = f(%SCBD)	0.02	0.136	<50	0.001	21
40	"	Amp = f(Mo)	-0.35	-0.530	<50	0.015	21
41	"	Amp = f(MBK)	-0.69	-1.960	90	0.168	21
42	"	Amp = f(MBD)	-0.03	-0.277	<50	0.004	21
43	"	(Amp/L) = f(%SCBK)	5.71	1.714	80	0.134	21
44	"	(Amp/L) = f(MBK)	-0.64	-2.508	95	0.249	21
45	Reach A, large or simple	Amp = f(%SCBK)	1.84	0.320	<50	0.017	8
46		Amp = f(%SCBD)	-0.70	-1.141	50	0.178	8
47		Amp = f(MBK)	1.85	2.818	95	0.570	8
48		Amp = f(MBD)	0.35	1.992	90	0.398	8

App. IVn. Sinuosity, Sin, and the channel perimeter sediment relationships for the Sturgeon River reaches.

Ref. No.	Data set	Relation	Exponent	Student's t of exponent	Two-tailed significance of t (%)	Coefficient of determination, r^2	Sample size
1	Reaches A to C	Sin = f(%SCBK)	2.15	1.493	50	0.088	6
2	Reaches A to C	Sin = f(%SCBD)	-0.03	-0.750	50	0.024	6
3	Reaches A to C	Sin = f(Mo)	0.10	0.421	50	0.008	6
4	Reaches A to C	Sin = f(Mfb)	1.27	2.978	95	0.343	6
5	Reaches A to C	Sin = f(MBK)	-0.20	-1.958	90	0.143	6
6	Reaches A to C	Sin = f(MBD)	-0.03	-0.771	50	0.025	6
7	Reaches E and F	Sin = f(%SCBK)	-0.04	-0.101	<50	0.003	5
8	Reaches E and F	Sin = f(Mo)	-0.15	-0.369	<50	0.043	5
9	Reaches E and F	Sin = f(Mfb)	-0.06	-0.176	<50	0.010	5
10	Reaches E and F	Sin = f(MBK)	0.09	0.505	<50	0.078	5
11	Reaches E and F	Sin = f(MBD)	-0.80	0.921	50	0.220	5
12	Reaches D to F	Sin = f(%SCBK)	-0.19	-0.473	<50	0.043	7
13	Reaches D to F	Sin = f(Mo)	0.10	0.729	50	0.096	7
14	Reaches D to F	Sin = f(Mfb)	0.11	0.708	<50	0.091	7
15	Reaches D to F	Sin = f(MBK)	0.14	0.843	50	0.124	7
16	Reaches D to F	Sin = f(MBD)	-0.03	-0.858	50	0.128	7
17	Reaches A to F	Sin = f(%SCBK)	0.12	0.589	<50	0.031	13
18	Reaches A to F	Sin = f(%SCBD)	0.02	1.059	50	0.092	13
19	Reaches A to F	Sin = f(Mo)	0.07	1.009	50	0.085	13

App. IVn. continued:

Ref. No.	Data set	Relation	Exponent	Student's t of exponent	Two-tailed significance of t (%)	Coefficient of determin-ation, r^2	Sample size
20	Reaches A to F	Sin = f(Mfb)	0.09	1.083	50	0.096	13
21	Reaches A to F	Sin = f(MBK)	-0.05	-0.738	50	0.047	13
22	Reaches A to F	Sin = f(MBD)	-0.03	-1.326	50	0.138	13
23	Reaches B to F	Sin = f(%SCBK)	0.26	1.224	50	0.143	11
24	Reaches B to F	Sin = f(%SCBD)	0.04	1.849	90	0.275	11
25	Reaches B to F	Sin = f(Mo)	0.13	1.952	90	0.297	11
26	Reaches B to F	Sin = f(Mfb)	0.15	1.993	90	0.306	11
27	Reaches B to F	Sin = f(MBK)	-0.08	-1.252	50	0.148	11
28	Reaches B to F	Sin = f(MBD)	-0.04	-2.032	90	0.314	11

App. IVo. The planform variables regressed on a dummy variable for the (Glacial Lake Edmonton silt and clay / no Glacial Lake Edmonton silt and clay) conditions.

Ref. No.	Data Set	Relation	Exponent	Student's t of exponent	Two-tailed significance of t (%)	Coefficient of determination, r^2	Sample size
1	Reaches A to F	Rc = f(dummy)	-0.55	-4.446	99.8	0.110	162
2	Reaches A to F	L = f(dummy)	-0.44	-4.654	99.8	0.119	162
3	Reaches A to F	Amp = f(dummy)	-0.15	-1.397	80	0.012	162

App. IVp. Planform interrelations for the Sturgeon River data. The natural planform data are used for the portions which have been artificially modified. All data are for simple meanders or small meanders of the compound pattern.

Ref. No.	Data Set	Relation	Exponent	Student's t of exponent	Two-tailed significance of t (%)	Coefficient of determination, r^2	Sample size
1	Reach A	L = f(Rc)	0.14	0.236	<50	0.589	12
2	Reach B	L = f(Rc)	0.73	6.406	99.8	0.719	18
3	Reach C	L = f(Rc)	0.60	10.482	99.8	0.714	46
4	Reach D	L = f(Rc)	0.62	8.796	99.8	0.707	34
5	Reach E	L = f(Rc)	0.67	11.694	99.8	0.845	27
6	Reach F	L = f(Rc)	0.47	6.117	99.8	0.619	25
7	Reaches A to C	L = f(Rc)	0.65	15.244	99.8	0.758	76
8	Reaches E and F	L = f(Rc)	0.53	10.652	99.8	0.694	52
9	Reaches A to F	L = f(Rc)	0.67	23.729	99.8	0.779	162
10	Reach A	Amp = f(L)	2.19	3.613	99	0.566	12
11	Reach B	Amp = f(L)	1.01	4.628	99.8	0.572	18
12	Reach C	Amp = f(L)	0.29	1.270	50	0.035	46
13	Reach D	Amp = f(L)	0.21	1.376	80	0.056	34
14	Reach E	Amp = f(L)	0.60	2.764	98	0.234	27
15	Reach F	Amp = f(L)	0.38	1.866	90	0.132	25
16	Reaches A to C	Amp = f(L)	0.47	3.294	99.8	0.128	76
17	Reaches E and F	Amp = f(L)	0.47	3.204	99	0.170	52
18	Reaches A to F	Amp = f(L)	0.54	7.140	99.8	0.242	162

App.IVq. Multiple regression relations for the Sturgeon River radius of curvature data, Rc. The asterisk (*) indicates that the coefficient of determination is significant at the 90% level or higher.

Reach	Planform variable	Ref. No.	Regressor	Exponent of regressor	t Statistic of exponent (%)	Regressor	Exponent of regressor	t Statistic of exponent (%)	Coefficient of determination, R^2	Sample size
A	Rc	1	%SCBD	0.54	0.975	Wo	0.31	0.483	0.121	10
		2	MBK	-0.46	-1.000	Wo	0.23	0.382	0.126	10
		3	MBD	-0.12	-1.150	Wo	0.29	0.478	0.160	10
		4	%SCBD	0.77	1.566	(W/Dx)o	0.51	1.586	0.332*	10
		5	MBK	-0.62	-1.477	(W/Dx)o	0.45	1.441	0.312*	10
		6	MBD	-0.16	-1.742	(W/Dx)o	0.50	1.626	0.371*	10
		7	%SCBD	0.39	0.744	Wfb	0.13	0.491	0.122	10
		8	MBD	-0.35	-0.743	Wfb	0.09	0.329	0.122	10
		9	MBK	-0.09	-0.880	Wfb	0.09	0.339	0.147	10
		10	%SCBD	0.47	0.771	(W/Dx) fb	0.05	0.109	0.093	10
		11	MBD	-0.43	-0.854	(W/Dx) fb	0.04	0.089	0.109	10
		12	MBK	-0.12	-1.014	(W/Dx) fb	0.13	0.275	0.142	10
B	Rc	13	%SCBK	-3.80	-0.160	%SCBD	-0.10	-0.050	0.008	7
		14	MBK	-0.07	-0.141	(W/Dx)o	1.024	0.759	0.126	7
		15	MBD	0.37	0.835	(W/Dx)o	1.14	0.929	0.252	7
		16	%SCBK	41.2	0.409	Wfb	-0.26	-0.034	0.161	4
		17	MBK	0.07	0.171	(W/Dx) fb	3.88	3.175	0.910*	4
		18	MBD	-0.19	0.803	(W/Dx) fb	3.27	3.849	0.944*	4
		19	%SCBK	25.3	0.632	%SCBD (W/Dx)o	-0.28 2.14	-0.145 0.918	0.226	7
C	Rc	20	%SCBK	1.68	0.415	Wo	0.61	0.322	0.060	8
		21	%SCBD	-0.05	-0.618	Wo	0.77	0.418	0.097	8
		22	MBD	0.03	0.421	Wo	0.90	0.468	0.061	8
		23	%SCBD	-0.06	-0.742	(W/Dx)o	0.46	0.560	0.121	8
		24	MBD	0.04	0.495	(W/Dx)o	0.45	0.514	0.070	8
		25	MBK	-0.84	-4.509	Wfb	-0.91	-1.888	0.965*	5
		26	MBD	-0.46	-1.487	Wfb	-1.90	-2.103	0.812*	5
		27	%SCBK	10.29	8.068	(W/Dx) fb	0.72	4.823	0.990*	5
		28	%SCBD	5.54	2.014	(W/Dx) fb	1.23	2.961	0.888*	5

App. IVq. continued:

Reach	Planform variable	Ref. No.	Regressor	Exponent of regressor	t Statistic of exponent (%)	Regressor	Exponent of regressor	t Statistic of exponent (%)	Coefficient of determination, R^2	Sample size
A,B,&C	Rc	29	%SCBK	-2.81	-0.971	%SCBD	0.03	0.303	0.041	25
		30	%SCBD	-0.04	-0.647	Wo	1.22	4.376	0.465*	25
		31	MBD	0.02	0.447	Wo	1.17	4.183	0.460*	25
		32	%SCBD	-0.35	-0.478	Wfb	0.68	2.347	0.306*	19
		33	%SCBK	-4.24	-1.854	(W/Dx) fb	1.16	3.421	0.530*	19
		34	MBK	0.13	0.727	(W/Dx) fb	1.25	3.457	0.447*	19
		35	MBD	0.01	0.241	Sc	-0.98	-2.752	0.279	5
		36	MBD	0.02	0.334	Sv	-0.66	-4.355	0.480	5
		37	%SCBK	3.45	1.385	%SCBD	-0.10	-1.431		
						(W/Dx)o	1.30	4.608	0.523*	25
D	Rc	38	%SCBK	-1.04	-1.010	%SCBD	-1.99	-2.030	0.670*	5
		39	MBK	0.70	0.710	MBD	1.46	1.200	0.420	5
		40	%SCBK	-0.64	-0.385	Wo	4.84	0.741	0.217	5
		41	MBK	0.24	0.239	Wo	4.00	0.664	0.183	5
		42	%SCBD	-1.47	-1.445	Wfb	0.28	0.146	0.511	5
		43	MBD	0.95	0.890	Wfb	0.44	0.186	0.265	5
		44	%SCBK	-1.19	-1.651	%SCBD	-2.09	-3.050		
						(W/Dx) fb	-2.74	-1.769	0.921*	5
		45	MBK	1.32	2.601	MBD	2.10	3.446		
						(W/Dx) fb	-4.37	-2.871	0.937*	5
E	Rc	46	%SCBK	1.10	0.300	Wo	2.27	0.510	0.120	3
		47	%SCBK	-0.46	-0.159	(W/Dx)o	-1.92	-0.921	0.300	3
		48	%SCBK	0.91	0.259	Wfb	1.59	0.484	0.106	3
		49	MBK	-1.35	-0.368	(W/Dx) fb	-0.56	-0.282	0.083	3
F	Rc	50	%SCBK	2.37	2.340	Wo	1.91	0.690	0.800*	6
		51	MBK	-1.05	-2.786	Wo	1.50	0.602	0.839*	6
		52	%SCBK	2.34	2.976	Wfb	2.51	1.310	0.849*	6
		53	MBK	-1.02	-4.718	Wfb	2.76	2.157	0.929*	6
		54	%SCBK	2.83	3.209	(W/Dx) fb	0.70	0.396	0.775*	6
		55	MBK	-1.26	-4.259	(W/Dx) fb	1.29	0.907	0.856*	6
D,E,&F	Rc	56	MBK	-0.57	-1.888	MBD	-0.006	-0.084	0.221	11

App. IVq. continued:

Reach	Planform variable	Ref. No.	Regressor	Exponent of regressor	t Statistic of exponent (%)	Regressor	Exponent of regressor	t Statistic of exponent (%)	Coefficient of determination, R^2	Sample size
D,E,&F	Rc	57	MBK	-0.53	-1.771	(W/Dx)o	0.16	0.389	0.230	11
		58	MBK	-0.71	-2.511	Wfb	1.65	1.624	0.352*	11
		59	%SCBK	0.87	1.505	(W/Dx) fb	-0.39	-0.536	0.151	11
		60	MBK	-0.56	-1.927	(W/Dx) fb	-0.16	-0.240	0.224	11
		61	Sv	-0.36	-0.996	Wo	4.19	2.225	0.276	6
A to F	Rc	62	%SCBK	0.66	3.444	Wo	1.29	4.195	0.420*	41
		63	%SCBD	0.05	2.021	Wo	1.25	3.750	0.313*	41
		64	MBK	-0.22	-3.405	Wo	1.38	4.434	0.417*	41
		65	MBD	-0.05	-2.218	Wo	1.34	4.000	0.326*	36
		66	%SCBK	0.51	2.459	(W/Dx)o	0.66	3.081	0.321*	41
		67	%SCBD	0.06	2.444	(W/Dx)o	0.82	3.822	0.320*	41
		68	MBK	-0.17	-2.569	(W/Dx)o	0.73	3.485	0.330*	41
		69	%SCBD	0.06	2.061	Wfb	0.54	1.809	0.167*	35
		70	Sc	-0.19	-2.061	Wo	1.20	3.597	0.316	7
		71	Sc	-0.20	-2.153	(W/Dx)o	0.74	3.423	0.299	7
		72	Sv	-0.30	-3.409	(W/Dx)o	0.59	2.872	0.398	7

App. IVr. Multiple regression relations for the Sturgeon River wavelength data, L. The asterisk (*) indicates that the coefficient of determination is significant at the 90% level or higher.

Reach	Planform variable	Ref. No.	Regressor	Exponent of regressor	t Statistic of exponent (%)	Regressor	Exponent of regressor	t Statistic of exponent (%)	Coefficient of determination, R^2	Sample size
A	L, small or simple	1	%SCBD	0.25	0.700	Wo	-0.68	0.117	0.402*	10
		2	MBK	-0.15	-0.495	Wo	-0.74	-1.810	0.382*	10
		3	MBD	-0.03	-0.475	Wo	-0.73	-1.760	0.380*	10
		4	%SCBD	0.28	0.704	(W/Dx)o	-0.31	-1.190	0.315*	10
		5	MBK	-0.14	-0.426	(W/Dx)o	-0.35	-1.375	0.285	10
		6	MBD	-0.03	-0.436	(W/Dx)o	-0.34	-1.331	0.286	10
		7	%SCBD	0.56	1.537	Wfb	-0.22	-1.163	0.310*	10
		8	MBK	-0.47	-1.347	Wfb	-0.26	-1.291	0.267	10
		9	MBD	-0.10	-1.350	Wfb	-0.25	-1.245	0.268	10
		10	%SCBD	0.17	0.413	(W/Dx) fb	-0.45	-1.451	0.367*	10
		11	MBK	-0.03	-0.087	(W/Dx) fb	-0.50	-1.676	0.352*	10
		12	MBD	0.004	0.047	(W/Dx) fb	-0.52	-1.631	0.352*	10
	L, large or simple	13	%SCBD	-1.68	-5.128	Wo	-0.61	-1.607	0.791*	10
		14	MBK	1.42	5.434	Wo	-0.37	1.063	0.809*	10
		15	MBD	0.33	6.418	Wo	-0.49	-1.580	0.855*	10
		16	%SCBD	-1.50	-3.847	(W/Dx)o	-0.04	-0.158	0.714*	10
		17	MBK	1.33	4.609	(W/Dx)o	0.04	0.199	0.780*	10
		18	MBD	0.31	4.973	(W/Dx)o	-0.01	-0.044	0.804*	10
		19	%SCBD	-1.40	-4.235	Wfb	-0.19	-1.124	0.757*	10
		20	MBD	1.32	4.539	Wfb	-0.05	-0.271	0.781*	10
		21	MBK	0.30	5.003	Wfb	-0.08	-0.516	0.811*	10
		22	%SCBD	-1.49	-3.580	(W/Dx) fb	-0.02	-0.076	0.714*	10
		23	MBK	1.33	4.319	(W/Dx) fb	0.03	0.116	0.779*	10
		24	MBD	0.33	4.809	(W/Dx) fb	-0.14	-0.541	0.812*	10
B	L, small	25	%SCBK	0.95	0.040	%SCBD	0.03	0.020	0.006	7
		26	MBK	-0.10	-2.051	(W/Dx)o	0.59	0.450	0.050	7
		27	MBD	0.28	0.615	(W/Dx)o	0.643	0.521	0.123	7
		28	%SCBK	21.7	0.551	%SCBD (W/Dx)o	-0.102 1.531	-0.053 0.665	0.129	7
		29	%SCBK	0.50	0.006	Wfb	-2.81	-0.419	0.162	4

App. IVr. continued.

Reach	Planform variable	Ref. No.	Regressor	Exponent of regressor	t Statistic of exponent (%)	Regressor	Exponent of regressor	t Statistic of exponent (%)	Coefficient of determination, R²	Sample size
B	L, small	30	MBK	0.33	3.562	(W/Dx) fb	3.05	3.562	0.993*	4
		31	MBD	0.19	1.009	(W/Dx) fb	2.89	4.282	0.955*	4
C	L, small or simple	32	%SCBK	-0.46	-0.176	Wo	0.70	0.572	0.063	8
		33	%SCBD	-0.06	-1.412	Wo	0.72	0.703	0.326	8
		34	MBD	0.05	1.059	Wo	0.92	0.820	0.230	8
		35	%SCBD	-0.06	-1.389	(W/Dx)o	0.18	0.363	0.278	8
		36	MBD	0.04	0.913	(W/Dx)o	0.17	0.314	0.143	8
		37	MBK	-0.39	-2.037	Wfb	-1.11	-2.235	0.921*	5
		38	MBD	-0.35	-11.880	Wfb	-1.49	-17.658	0.997*	5
		39	%SCBK	7.15	1.582	(W/Dx) fb	0.29	0.550	0.736*	5
		40	%SCBD	6.17	11.757	(W/Dx) fb	0.58	7.284	0.992*	5
	L, large or simple	41	%SCBK	2.[illegible]	0.505	Wo	0.10	0.159	0.049	8
		42	%SCBD	-0.04	-0.609	Wo	0.09	0.084	0.069	8
		43	MBD	0.02	0.213	Wo	0.02	0.018	0.009	8
		44	%SCBD	-0.07	-1.019	(W/Dx)o	1.22	1.108	0.252	8
		45	MBD	0.04	0.564	(W/Dx)o	1.09	0.912	0.150	8
		46	MBK	-0.98	-2.482	Wfb	1.18	1.151	0.761*	5
		47	MBD	-0.67	-1.986	Wfb	0.10	0.101	0.672*	5
		48	%SCBK	-1.47	-0.413	(W/Dx) fb	1.42	3.416	0.883*	5
		49	%SCBD	-1.37	-0.624	(W/Dx) fb	1.36	4.097	0.894*	5
A,B,&C	L, small or simple	50	%SCBK	-2.32	-1.033	%SCBD	-0.0005	-0.008	0.051	25
		51	%SCBD	-0.05	-0.967	Wo	0.83	3.550	0.367*	25
		52	MBD	0.03	0.842	Wo	0.76	3.242	0.360*	25
		53	%SCBK	0.91	0.377	%SCBD	-0.07	-0.975		
						(W/Dx)o	0.67	2.453	0.262*	25
		54	MBD	0.03	0.632	Sc	-0.64	-2.296	0.237	5
		55	MBD	0.03	0.731	Sv	-0.48	-4.052	0.459	5
		56	%SCBD	-0.27	-0.444	Wfb	0.35	1.463	0.158*	19
		57	%SCBK	-2.75	-1.342	(W/Dx) fb	0.66	2.170	0.328*	18
		58	MBK	0.10	0.643	(W/Dx) fb	0.71	2.301	0.271*	19

App. IVr. continued:

Reach	Planform variable	Ref. No.	Regressor	Exponent of regressor	t Statistic of exponent (%)	Regressor	Exponent of regressor	t Statistic of exponent (%)	Coefficient of determination, R^2	Sample size
A,B,&C	L, large or simple	59	%SCBD	-0.03	-0.529	Wo	1.06	3.607	0.420*	21
		60	MBK	-0.26	-1.304	Wo	1.14	3.965	0.468*	21
		61	MBD	0.02	0.441	Wo	1.01	3.474	0.410*	21
		62	%SCBD	-0.04	-0.616	(W/Dm)o	0.80	3.213	0.365*	21
		63	MBK	-0.19	-0.988	(W/Dm)o	0.82	3.345	0.385*	21
		64	MBD	0.03	0.612	(W/Dm)o	0.75	3.095	0.365*	21
		65	%SCBD	-0.02	-0.408	Sc	-0.55	-3.108	0.350	5
		66	MBD	0.03	0.511	Sc	-0.53	-3.014	0.353	5
		67	%SCBD	-0.01	-0.235	Sv	-0.741	-2.913	0.321	5
		68	MBD	0.08	1.589	Sv	-0.81	-3.365	0.403	5
		69	Sv	-0.70	-4.183	Wo	1.00	4.802	0.701*	5
		70	Sv	-0.68	-3.578	(W/Dm)o	0.71	3.789	0.621	5
		71	%SCBD	-0.05	-1.284	Sv	-0.73	-4.383		
						Wo	1.04	5.040	0.728*	5
		72	MBD	0.06	1.646	Sv	-0.76	-4.632		
						Wo	0.95	4.736	0.742*	5
		73	%SCBD	-0.06	-1.227	Sv	-0.70	-3.743		
						(W/Dm)o	0.76	4.020	0.652	5
		74	MBD	0.07	1.703	Sv	-0.75	-4.044		
						(W/Dm)o	0.68	3.791	0.676*	5
		75	%SCBD	-1.07	-2.910	Wfb	0.05	0.217	0.391*	21
		76	%SCBK	-0.65	-0.277	(W/Dm)fb	1.11	3.336	0.445*	21
		77	MBK	0.001	0.005	(W/Dm)fb	1.13	3.429	0.442*	21
D	L	78	%SCBK	-0.45	-0.730	%SCBD	-1.08	-1.840	0.640	5
		79	MBK	0.20	0.490	MBD	0.78	1.100	0.390	5
		80	%SCBK	-0.19	-0.193	Wo	2.35	0.620	0.179	5
		81	MBK	0.03	0.048	Wo	1.99	0.576	0.164	5
		82	%SCBD	-0.84	-1.509	Wfb	-0.10	-0.088	0.543	5
		83	MBD	0.55	0.930	Wfb	-0.007	-0.005	0.318	5
		84	%SCBK	-0.54	-1.570	%SCBD	-1.14	-3.499		
						(W/Dm)fb	-1.73	-2.345	0.944*	5

App. IVr. continued:

Reach	Planform variable	Ref. No.	Regressor	Exponent of regressor	t Statistic of exponent (%)	Regressor	Exponent of regressor	t Statistic of exponent (%)	Coefficient of determination, R^2	Sample size
D	L	85	MBK	0.65	2.619	MBD	1.15	3.883		
						(W/Dx)fb	-2.58	-3.469	0.953*	5
E	L	86	%SCBK	2.27	0.651	Wo	1.97	0.460	0.181	3
		87	%SCBK	0.85	0.306	(W/Dx)o	-1.88	-0.949	0.377	3
		88	%SCBK	2.105	0.619	Wfb	1.37	0.431	0.173	3
		89	MBK	-1.26	-0.366	(W/Dx)fb	-1.27	-0.663	0.288	3
F	L, small or simple	90	%SCBK	1.52	2.151	Wo	1.22	0.633	0.771*	6
		91	MBK	-0.65	-2.236	Wo	1.06	0.554	0.777*	6
		92	%SCBK	1.39	3.283	Wfb	2.25	2.180	0.897*	6
		93	MBK	-0.60	-5.135	Wfb	2.41	3.510	0.952*	6
		94	%SCBK	1.86	3.413	(W/Dx)fb	1.05	0.966	0.798*	6
		95	MBK	-0.81	-4.385	(W/Dx)fb	1.43	1.592	0.867*	6
	L, large or simple	96	%SCBK	1.21	1.382	Wo	-1.09	-0.460	0.409	6
		97	MBK	-0.39	-0.942	Wo	-0.73	-0.267	0.254	6
		98	%SCBK	1.14	1.456	Wfb	-0.96	-0.499	0.416	6
		99	MBK	-0.36	-0.999	Wfb	-0.54	-0.254	0.252	6
		100	%SCBK	0.97	1.302	(W/Dx)fb	-0.03	-0.021	0.368	6
		101	MBK	-0.33	-0.942	(W/Dx)fb	0.05	0.030	0.236	6
D,E,&F	L, small or simple	102	MBK	-0.41	-2.001	MBD	0.02	0.539	0.280*	11
		103	MBK	-0.40	-1.959	(W/Dx)o	0.19	0.662	0.288*	11
		104	MBK	-0.50	-2.458	Wfb	0.76	1.032	0.320*	11
		105	%SCBK	0.79	2.032	(W/Dx)fb	-0.13	-0.272	0.242	11
		106	MBK	-0.44	-2.161	(W/Dx)fb	0.07	0.160	0.266	11
		107	Sv	-0.14	-0.511	Wo	2.67	1.940	0.230	6
A to F	L, small or simple	108	%SCBK	0.61	4.202	Wo	0.86	3.687	0.435*	41
		109	%SCBD	0.04	1.825	Wo	0.82	3.029	0.239*	41
		110	MBK	-0.19	-3.833	Wo	0.93	3.865	0.403*	41
		111	MBD	-0.04	-2.085	Wo	0.88	3.277	0.257*	36
		112	%SCBK	0.52	3.274	(W/Dx)o	0.40	2.465	0.338*	41
		113	%SCBD	0.54	2.164	(W/Dx)o	0.54	3.091	0.346*	41

App. IVr. continued:

Reach	Planform variable	Ref. No.	Regressor	Exponent of regressor	t Statistic of exponent (%)	Regressor	Exponent of regressor	t Statistic of exponent (%)	Coefficient of determination, R^2	Sample size
A to F	L, small or simple	114	MDK	-0.16	-3.072	(W/Dm)o	0.47	2.918	0.320*	41
		115	%SCBD	0.05	1.968	Wfb	0.20	0.840	0.114*	35
		116	Sc	-0.18	-2.573	Wo	0.77	2.983	0.295	7
		117	Sc	-0.19	-2.651	(W/Dm)o	0.48	2.862	0.284	7
		118	Sv	-0.26	-3.794	(W/Dm)o	0.35	2.194	0.385	7

App.IVs. Multiple regression relations for the Sturgeon River amplitude data, Amp. The asterisk (*) indicates that the coefficient of determination is significant at the 90% or higher level.

Reach	Planform Variable	Ref. No.	Regressor	Exponent of regressor	t Statistic of exponent (%)	Regressor	Exponent of regressor	t Statistic of exponent (%)	Coefficient of determination, R^2	Sample size
A	Amp, small or simple	1	%SCBD	0.35	0.306	Wo	-1.90	-1.414	0.209	10
		2	MBK	-0.20	-0.207	Wo	-1.99	-1.537	0.204	10
		3	MBD	-0.02	-0.083	Wo	-2.02	-1.539	0.201	10
		4	%SCBD	0.13	0.118	(W/Dx)o	-1.31	-1.800	0.376*	10
		5	MBK	0.004	0.005	(W/Dx)o	-1.35	-1.926	0.374*	10
		6	MBD	0.03	0.140	(W/Dx)o	-1.39	-1.949	0.376*	10
		7	%SCBD	1.13	0.949	Wfb	-0.40	-0.653	0.139	10
		8	MBK	-0.91	-0.810	Wfb	-0.48	-0.736	0.111	10
		9	MBD	-0.18	-0.727	Wfb	-0.44	-0.676	0.096	10
		10	%SCBD	0.15	0.112	(W/Dx) fb	-1.20	-1.220	0.247	10
		11	MBK	0.10	0.095	(W/Dx) fb	-1.30	-1.375	0.246	10
		12	MBD	0.09	0.326	(W/Dx) fb	-1.45	-1.437	0.257	10
	Amp, large or simple	13	%SCBD	-3.62	-6.162	Wo	-1.39	-1.934	0.845*	10
		14	MBK	3.24	6.022	Wo	-0.85	-1.339	0.870*	10
		15	MBD	0.77	9.506	Wo	-1.12	-2.372	0.930*	10
		16	%SCBD	-3.84	-5.873	(W/Dx)o	-0.75	-1.742	0.834*	10
		17	MBK	3.30	6.860	(W/Dx)o	-0.51	-1.411	0.673*	10
		18	MBD	0.78	9.618	(W/Dx)o	-0.66	-2.417	0.931*	10
		19	%SCBD	-1.14	-5.379	Wfb	-0.57	-1.925	0.845*	10
		20	MBK	2.91	5.537	Wfb	-0.26	-0.844	0.852*	10
		21	MBD	0.67	6.917	Wfb	-0.33	-1.311	0.898*	10
		22	%SCBD	-3.71	-4.673	(W/Dx) fb	-0.52	-0.854	0.785*	10
		23	MBK	3.27	5.825	(W/Dx) fb	-0.36	-0.738	0.843*	10
		24	MBD	0.83	8.915	(W/Dx) fb	-0.83	-2.317	0.928*	10
B	Amp, small	25	%SCBK	-1.50	-0.051	%SCBD	0.75	0.281	0.020	7
		26	MBK	-0.22	-3.07	(W/Dx)o	0.43	0.210	0.028	7
		27	MBD	-0.03	-0.044	(W/Dx)o	0.26	0.129	0.005	7
		28	%SCBK	6.95	0.109	%SCBD (W/Dx)o	0.70 0.63	0.227 0.169	0.029	7
		29	%SCBK	-90.2	-1.103	Wfb	-6.70	-1.095	0.653	4

App.IVa. continued:

Reach	Planform variable	Ref. No.	Regressor	Exponent of regressor	t Statistic of exponent (%)	Regressor	Exponent of regressor	t Statistic of exponent (%)	Coefficient of determination, R^2	Sample size
B	Amp, small	30	MBK	0.60	0.527	(W/Dx) fb	2.74	0.859	0.488	4
		31	MBD	-0.02	-0.022	(W/Dx) fb	2.63	0.723	0.346	4
C	Amp, small or simple	32	%SCBK	-2.67	-0.375	Wo	3.20	0.960	0.164	8
		33	%SCBD	-0.06	-0.437	Wo	3.07	0.935	0.175	8
		34	MBD	0.04	0.275	Wo	3.22	0.947	0.153	8
		35	%SCBD	-0.05	-0.330	(W/Dx)o	-0.15	-0.094	0.028	8
		36	MBD	-0.00008	-0.0005	(W/Dx)o	-0.30	-0.178	0.007	8
		37	MBK	-0.11	-0.071	Wfb	-0.51	-0.121	0.023	5
		38	MBD	-0.84	-0.821	Wfb	-0.10	-0.035	0.268	5
		39	%SCBK	-5.99	-0.290	(W/Dx) fb	0.53	0.221	0.043	5
		40	%SCBD	9.03	0.748	(W/Dx) fb	-0.13	-0.073	0.229	5
	Amp, large or simple	41	%SCBK	8.72	0.900	Wo	3.37	0.870	0.185	8
		42	%SCBD	-0.01	-0.077	Wo	1.49	0.536	0.054	8
		43	MBD	-0.07	-0.388	Wo	1.19	-0.430	0.081	8
		44	%SCBD	-0.03	-0.170	(W/Dx)o	1.78	0.550	0.059	8
		45	MBD	-0.06	-0.320	(W/Dx)o	1.20	0.373	0.073	8
		46	MBK	-1.85	-2.506	Wfb	1.77	0.926	0.774*	5
		47	MBD	-1.52	6.520	Wfb	-0.09	-0.137	0.958*	5
		48	%SCBK	-3.85	-0.465	(W/Dx) fb	2.71	2.795	0.828*	5
		49	%SCBD	2.07	0.379	(W/Dx) fb	2.39	2.887	0.823*	5
A,B,&C	Amp, small or simple	50	%SCBK	-2.61	-0.767	%SCBD	-0.02	-0.232	0.036	25
		51	%SCBD	-0.05	-0.486	Wo	0.12	0.235	0.012	25
		52	MBD	0.01	0.166	Wo	0.06	0.124	0.002	25
		53	%SCBK	-5.32	-1.323	%SCBD	0.03	0.272	0.101	25
						(W/Dx)o	-0.56	-1.236		
		54	MBD	0.02	0.173	Sc	-0.02	-0.034	0.002	5
		55	MBD	0.01	0.095	Sv	-0.14	-0.500	0.013	5
		56	%SCBD	0.70	0.693	Wfb	-0.16	-0.399	0.052	19
		57	%SCBK	0.63	0.162	(W/Dx) fb	-0.17	-0.301	0.009	19
		58	MBK	-0.10	-0.361	(W/Dx) fb	-0.17	-0.309	0.015	19

App. IVa. continued:

Reach	Planform variable	Ref. No.	Regressor	Exponent of regressor	t Statistic of exponent (%)	Regressor	Exponent of regressor	t Statistic of exponent (%)	Coefficient of determination, R^2	Sample size
A,B,&C	Amp,large or simple	59	%SCBD	-0.003	-0.028	Wo	0.55	0.854	0.040	21
		60	MBK	-0.85	-2.414	Wo	0.92	1.623	0.275*	21
		61	MBD	-0.04	-0.393	Wo	0.58	0.912	0.048	21
		62	%SCBD	-0.003	-0.024	(W/Dx)o	0.34	0.653	0.024	21
		63	MBK	-0.78	-2.197	(W/Dx)o	0.57	1.203	0.230*	21
		64	MBD	-0.04	-0.329	(W/Dx)o	0.35	0.692	0.030	21
		65	%SCBD	0.02	0.153	Sc	0.05	0.133	0.002	5
		66	MBD	-0.03	-0.259	Sc	0.03	0.077	0.004	5
		67	%SCBD	-0.04	-0.496	Sv	-1.76	-5.541	0.631	5
		68	MBD	0.05	0.752	Sv	-1.79	-5.604	0.637	5
		69	Sv	-1.72	-5.649	Wo	0.46	1.207	0.654	5
		70	Sv	-1.72	-5.480	(W/Dx)o	0.20	0.649	0.634	5
		71	%SCBD	-0.06	-0.738	Sv	-1.75	-5.626	0.664*	5
						Wo	0.51	1.307		
		72	MBD	0.04	0.592	Sv	-1.77	-5.541	0.661*	5
						Wo	0.42	1.087		
		73	%SCBD	-0.05	-0.653	Sv	-1.75	-5.431	0.643	5
						(W/Dx)o	0.25	0.770		
		74	MBD	0.05	0.677	Sv	-1.77	-5.414	0.644	5
						(W/Dx)o	0.181	0.567		
		75	%SCBD	-2.23	-2.242	Wfb	-0.97	-2.558	0.337*	21
		76	%SCBK	7.62	1.890	(W/Dx)fb	1.14	1.985	0.295*	21
		77	MBK	-0.64	-2.040	(W/Dx)fb	1.04	1.071	0.317*	21
D	Amp	78	%SCBK	0.47	1.251	%SCBD	-0.10	-0.27	0.590	5
		79	MBK	-0.34	-1.342	MBD	0.04	0.121	0.641	5
		80	%SCBK	0.59	1.524	Wo	-0.46	-0.303	0.593	5
		81	MBK	-0.37	-1.678	Wo	-0.08	-0.058	0.634	5
		82	%SCBD	-0.27	-1.318	Wfb	-0.92	-2.365	0.808*	5
		83	MBK	0.21	1.053	Wfb	-0.87	-1.992	0.769*	5
		84	%SCBK	0.41	1.537	%SCBD	-0.13	-0.520	0.895*	5
						(W/Dx)fb	-0.98	-1.704		

App. IVa. continued:

Reach	Planform variable	Ref. No.	Regressor	Exponent of regressor	t Statistic of exponent (%)	Regressor	Exponent of regressor	t Statistic of exponent (%)	Coefficient of determination, R^2	Sample size
D	Amp	85	MBK	-0.21	-0.835	MBD	-0.17	-0.571	0.854*	5
						(W/Dx) fb	-0.92	-1.219		
E	Amp	86	%SCBK	3.13	1.171	Wo	1.23	0.370	0.410	3
		87	%SCBK	2.14	1.045	(W/Dx)o	-1.46	-0.991	0.579	3
		88	%SCBK	3.02	1.164	Wfb	0.85	0.350	0.408	3
		89	MBK	-0.90	-0.353	(W/Dx) fb	-1.81	-1.313	0.465	3
F	Amp, small or simple	90	%SCBK	0.29	0.363	Wo	1.67	0.751	0.330	6
		91	MBK	-0.14	-0.395	Wo	1.60	0.709	0.338	6
		92	%SCBK	0.17	0.356	Wfb	2.77	2.405	0.729*	6
		93	MBK	-0.12	-0.637	Wfb	2.70	2.516	0.751*	6
		94	%SCBK	0.76	1.234	(W/Dx) fb	1.44	1.171	0.456	6
		95	MBK	-0.36	-1.510	(W/Dx) fb	1.63	1.406	0.53[illegible]*	6
	Amp, large or simple	96	%SCBK	1.11	0.474	Wo	-2.70	-0.425	0.080	6
		97	MBK	-0.12	-0.121	Wo	-1.45	-0.217	0.016	6
		98	%SCBK	0.16	0.075	Wfb	2.19	0.425	0.080	6
		99	MBK	0.17	0.206	Wfb	2.73	0.547	0.091	6
		100	%SCBK	0.66	0.341	(W/Dx) fb	1.62	0.417	0.078	6
		101	MBK	-0.07	-0.080	(W/Dx) fb	1.49	0.371	0.044	6
D,E,&F	Amp, small or simple	102	MBK	-0.32	-2.019	MBD	0.06	1.671	0.407*	11
		103	MBK	-0.35	-2.034	(W/Dx)o	0.17	0.702	0.305*	11
		104	MBK	-0.36	-2.011	Wfb	-0.27	-0.419	0.289*	11
		105	%SCBK	0.83	2.676	(W/Dx) fb	0.12	0.336	0.416*	11
		106	MBK	-0.38	-2.302	(W/Dx) fb	0.34	0.897	0.321*	11
		107	Sv	0.15	0.652	Wo	1.35	1.115	0.177	6
A to F	Amp, small or simple	108	%SCBK	0.62	2.556	Wo	0.15	0.394	0.148*	41
		109	%SCBD	0.02	0.759	Wo	0.10	0.243	0.016	41
		110	MBK	-0.19	-2.374	Wo	0.23	0.580	0.130*	41
		111	MBD	-0.03	-1.114	Wo	0.16	0.389	0.033	36
		112	%SCBK	0.62	2.529	(W/Dx)o	-0.04	-0.167	0.145*	41
		113	%SCBD	0.02	0.788	(W/Dx)o	0.08	0.306	0.017	41
		114	MBK	-0.18	-2.303	(W/Dx)o	0.05	0.190	0.123*	41

App. IVs. continued:

Reach	Planform variable	Ref. No.	Regressor	Exponent of regressor	t Statistic of exponent (%)	Regressor	Exponent of regressor	t Statistic of exponent (%)	Coefficient of determination, R^2	Sample size
A to F	Amp, small or simple	115	%SCBD	0.05	1.213	Wfb	-0.42	-1.426	0.117*	35
		116	Sc	-0.16	-1.420	Wo	0.07	0.170	0.051	7
		117	Sc	-0.16	-1.426	(W/Dx)o	0.05	0.191	0.052	7
		118	Sv	-0.20	-1.753	(W/Dx)o	-0.05	-0.193	0.076	7

App. IVt. Multiple regression relations for the Sturgeon River sinuosity data, Sin. The asterisk (*) indicates that the coefficient of determination is significant at the 90% or higher level.

Reaches	Planform Variable	Ref. No.	Regressor	Exponent of regressor	t Statistic of exponent (%)	Regressor	Exponent of regressor	t Statistic of exponent (%)	Coefficient of determination, R^2	Sample size
A,B,&C	Sin	1	%SCBK	2.72	1.836	%SCBD	-0.06	-1.293	0.153	6
		2	%SCBD	-0.01	-0.266	Wo	-0.69	-3.925	0.426	6
		3	MBD	-0.01	-0.350	Wo	-0.69	-3.930	0.427	6
		4	MBD	0.01	0.247	Sc	0.89	5.313	0.573	5
		5	MBD	-0.001	-0.046	Sv	0.50	7.339	0.717*	5
		6	%SCBK	0.84	0.510	%SCBD	-0.02	-0.453	0.298	6
						(W/Dx)o	-0.39	-2.086		
		7	%SCBD	0.87	2.465	Wfb	-0.36	-2.635	0.537*	6
		8	%SCBK	4.46	2.965	(W/Dx) fb	-0.21	-0.963	0.410	6
		9	MBK	-0.38	-4.064	(W/Dx) fb	-0.28	-1.441	0.550*	6
D,E,&F	Sin	10	MBK	0.15	1.395	MBD	-0.03	-1.157	0.247	7
		11	MBK	0.16	1.472	(W/Dx)o	-0.07	-0.456	0.182	7
		12	MBK	0.14	1.295	Wfb	0.39	0.959	0.224	7
		13	%SCBK	-0.28	-1.314	(W/Dx) fb	-0.10	-0.369	0.144	7
		14	MBK	0.18	1.648	(W/Dx) fb	-0.17	-0.680	0.198	7
		15	Sv	-0.23	-1.781	Wo	-0.43	-0.644	0.301	6
A to F	Sin	16	%SCBK	-0.03	-0.343	Wo	-0.72	-4.613	0.359*	13
		17	%SCBD	0.005	0.433	Wo	-0.71	-4.572	0.360*	13
		18	MBK	-0.01	-0.289	Wo	-0.70	-4.496	0.358*	13
		19	MBD	-0.007	-0.599	Wo	-0.70	-4.444	0.363*	13
		20	%SCBK	0.04	0.401	(W/Dx)o	-0.33	-2.983	0.190	13
		21	%SCBD	0.001	0.116	(W/Dx)o	-0.33	-2.887	0.187	13
		22	MBK	-0.03	-0.894	(W/Dx)o	-0.33	-2.978	0.203	13
		23	%SCBD	0.007	0.543	Wfb	-0.34	-2.595	0.195	13
		24	Sc	-0.03	-0.659	Wo	-0.71	-4.633	0.364	7
		25	Sc	-0.02	-0.460	(W/Dx)o	-0.33	-2.953	0.191	7
		26	Sv	0.05	0.988	(W/Dx)o	-0.30	-2.714	0.207	7